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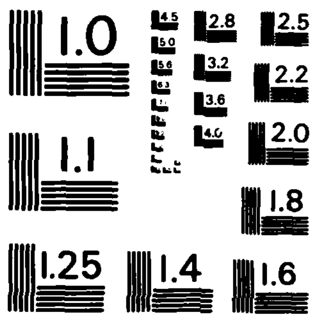

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ESTIMATING COMPUTER COMMUNICATION NETWORK PERFORMANCE
USING NETWORK SIMULATIONS

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A dissertation submitted to the School of Engineering, University of Dayton, Dayton, Ohio in partial fulfillment of the requirements for the degree Doctor of Philosophy in Engineering, Major in Electrical Engineering.

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A generalized queueing model simulation of store-and-forward computer communication networks is developed and implemented using Simulation Language for Alternative Modeling (SLAM). The model includes an ACK/NAK data link protocol, four-level message precedence, finite queues and a response traffic scenario. Network performance, indicated by average message delay and message throughput, is estimated using the simulation model.

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Albert B. Garcia

UNIVERSITY OF DAYTON

Dayton, Ohio

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ESTIMATING COMPUTER COMMUNICATION NETWORK PERFORMANCE USING NETWORK SIMULATIONS

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ABSTRACT

ESTIMATING COMPUTER COMMUNICATION NETWORK PERFORMANCE USING NETWORK SIMULATIONS

Albert B. Garcia, Ph.D.
University of Dayton, 1985

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A generalized queueing model simulation of store-and-forward computer communication networks is developed and implemented using Simulation Language for Alternative Modeling (SLAM). A baseline simulation mcdel is validated by comparison with published analytic models. The baseline model is expanded to include an ACK/NAK data link protocol, four-level message precedence, finite queues and a response traffic scenario. Network performance, as indicated by average message delay and message throughput, is estimated using the simulation model.

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Special thanks for the opportunity to pursue my graduate education are due Colonel Roger V. Sheffield, US Army Signal Corps. Skill, Endurance, Spirit!

CHAPTER I

INTRODUCTION

Motivation

The technological advances in the electronics industry during the past decade have spawned enormous growth in the computer and data communication fields. Capabilities formerly available only at large and expensive fixed computing centers are widely available due to two general trends--packaging of greater capabilities into smaller affordable minicomputers, and distributing the capabilities of fixed computing centers via data communications. The result has been the growth of integrated communication and computing networks. Some examples serve to illustrate this growth.

Remote public banking terminals and electronic funds transfer are now commonplace in the finance industry. Retail point-of-sale systems use intelligent terminals as cash registers to collect information on cash flow and inventory status. Large information banks with remote access are used by law-enforcement, medical, insurance, transportation and government agencies. Mobile computer terminals used by police, fire and medical personnel extend

computer systems to locations where services are rendered. Tactical military computer communication networks support mobile command and control systems.

All too often computer networks evolve in response to a current need without regard for future requirements. As the network grows in size, the complexity increases quickly beyond simple understanding. Unfortunately, sophisticated systems have been designed without a complete understanding of future workloads.[1] Sometimes computer networks are planned assuming that existing communication channels are adequate. This attractive assumption is made by computer network designers who have little or no control over communication resources. Adequate tools are needed to evaluate network performance, to determine if performance will meet objectives and to understand how performance can be improved.

A computer communication network design can be analyzed using a mathematical analytic model, a computer simulation model or by constructing a working model. All three approaches have been used. Unfortunately, present analytic models fail to capture all the characteristics of a mature network design. Work continues on developing useful analytic models.[4,17,21,26] The Department of Defense Advanced Research Projects Agency's ARPANET network [28] and the University of Hawaii's ALOHA network [18] are two examples of working research networks. These networks

and others provide a testbed for experimenting with specific design questions.

Computer simulation models are able to incorporate greater detail than analytic models. Simulation models cost less to implement than working models. Using a simulation model, a designer has the flexibility to vary the configuration and processing details of a network design.

Purpose

The purpose of this research is to develop and implement a generalized simulation model to evaluate computer communication networks by estimating network performance. The resulting simulation allows reasonably realistic and quantitative performance comparisons of network design alternatives.

In chapter II a classical analytic network model is presented. The analytic model is used to validate a baseline simulation model, forming the basis for a generalized full simulation model. Chapter III describes the baseline simulation, the validation results and the full simulation model. A hypothetical network is simulated in chapter IV to demonstrate the features of the full simulation. The final chapter summarizes the results of this research.

CHAPTER II

A CLASSICAL ANALYTIC NETWORK MODEL

Background

The Network

A computer communication network consists of a collection of nodes connected by data communication links. Each node contains computing resources which act on messages flowing in the network. The nodal structures of a computer communication network include input/output terminals, host computers and switching computers. The data communication links are two-way communication channels through which the messages pass. Figure 1, which is derived from Davies [6], shows the structure of a computer communication network partitioned into two separate subnetworks: the communication subnetwork and the user-resource subnetwork. The partitioning into two subnetworks is conceptual and may not represent physical boundaries for a specific computer communication network.

The user-resource subnetwork host computers provide the processing services and file storage for users of a computer facility and interface the user into the comunication subnetwork. The communication subnetwork

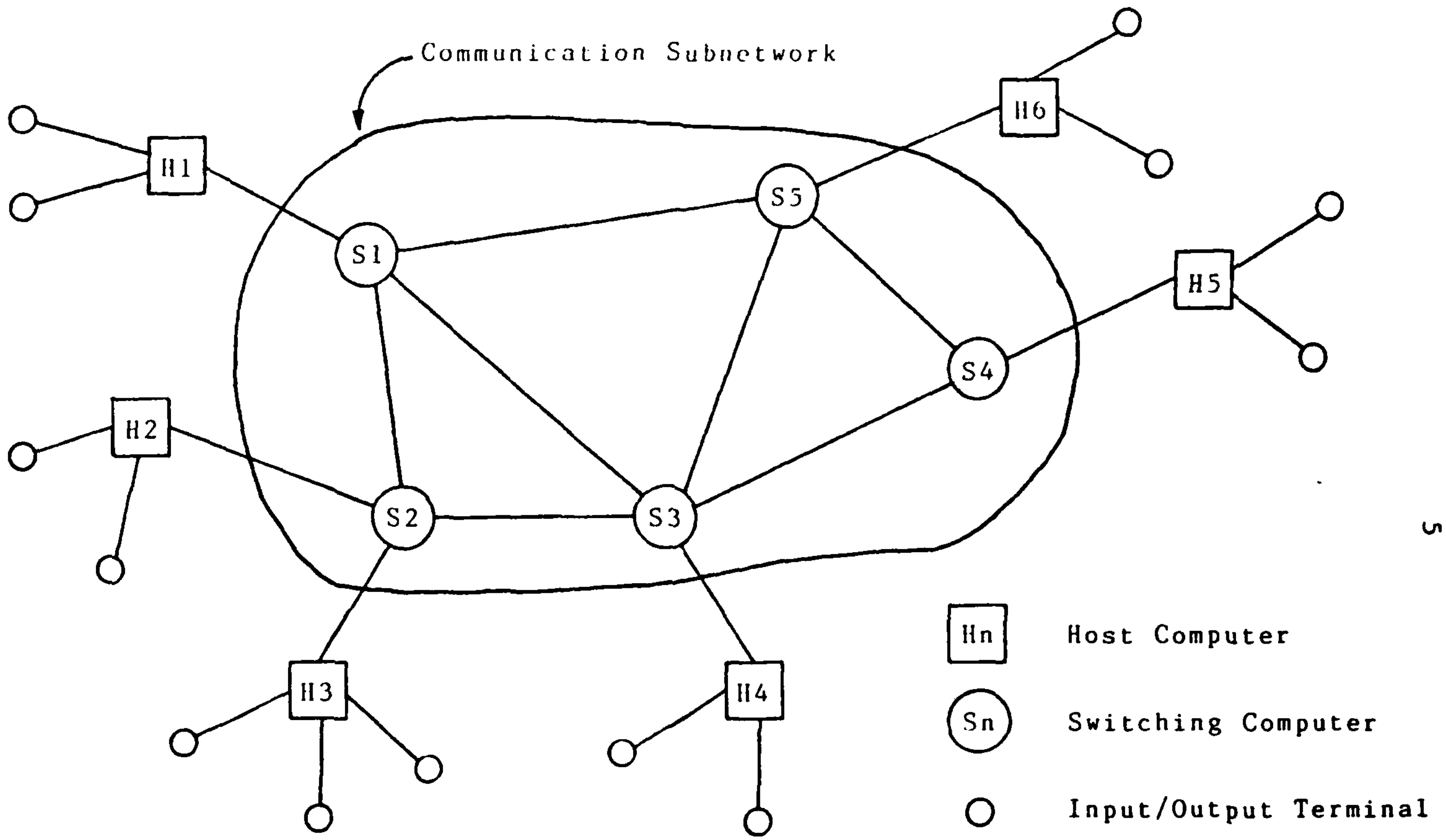


Figure 1: Structure of a computer communication network.

switching computers are responsible for establishing a path from source node to destination node for each message. This is accomplished by either circuit switching, message switching or packet switching.[15]

In circuit switching a complete path through the network is established from source to destination. After the path is established the message is transmitted. Circuit switching is similiar to the method used for a common telephone system.

In message switching the switching computers use a store-and-forward method of relaying messages. That is, messages are completely received at one node before they begin transmission to the next node. If the outgoing link from a node is busy, the message waits in a queue until the link becomes free. A message switched network was assumed in this study as it is well suited for computer data flow.[15]

Packet switching is basically the same as message switching except that messages are divided into packets, or smaller messages, before transmission. The individual packets are relayed through the network using the same store-and-forward method as message switching and are assembled at the destination to form the original message.

The activities of the communication subnetwork are usually transparent to the user. The activities include routing, acknowledging, detecting and correcting errors,

and scheduling messages for transmission. The emphasis of this study is the performance evaluation and design of the communication subnetwork. Unless otherwise stated, the term computer communication network in this paper refers to the communication subnetwork.

The messages flowing in the computer communication network are described by their source, destination, creation time, length and precedence. Messages may also contain additional information such as a type identification, serial number and requests for special facilities. Standards defining message architectures have been established by the International Telecommunications Union (ITU) and the International Standards Organization (ISO).[18] The message structure used in this study is compatable with ITU standards. In practice, each computer communication network uses a unique message structure.

The operating rules, or protocol, for the entire computer communication network are a description of the decision processes and conventions implemented within the network. Network protocol is usually organized in a series of layers or levels. One widely accepted protocol structure is the ISO reference model. This model, shown in figure 2 which is derived from Tannenbaum [28], has 7 layers. Layers 1, 2 and 3 are contained within the communication subnetwork. The physical layer is concerned with the mechanical, electrical and procedural aspects of

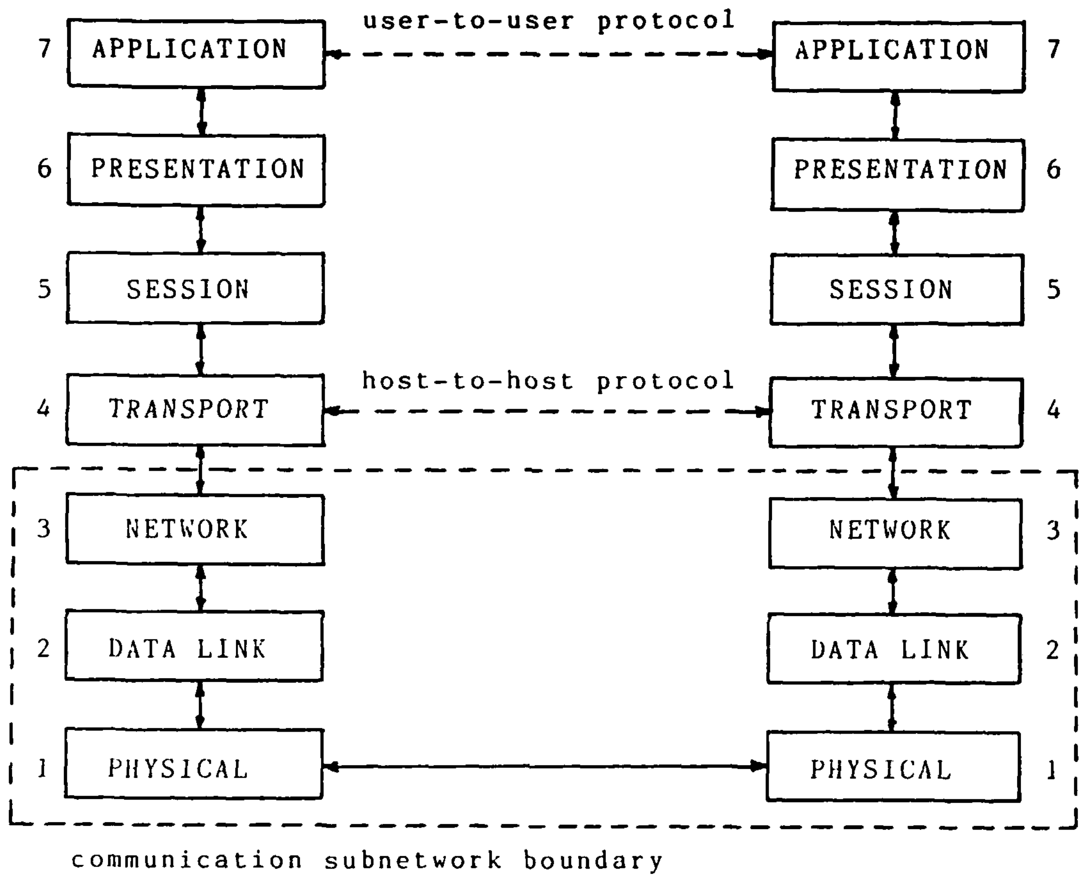


Figure 2: ISO protocol reference model.

communications equipment. Layers 2 and 3 describe how the communication subnetwork will function. These two layers are the principle focus of the computer communication simulation model implemented in this study. The structure of the network and data link protocol layers contain

parameters which directly influence overall computer communication network performance.

Network Performance Measurement

The performance of a computer communication network is usually measured in terms of message delay, throughput, cost and reliability.[15] Other parameters have also been explored such as a measure of active resources and a concept of fairness.[29,30]

Message delay is a measure of the time required for a message to travel from source to destination. Interactive users usually have short messages and are primarily interested in the amount of system delay. Throughput is a measure of the amount of information per unit time which can be passed through a network. Users transmitting long messages or files are interested in throughput performance. The total cost for construction and operation of a network can be allocated among the communication links as a function of link capacity. The function can contain both fixed and variable components. Linear, logarithmic and power-law cost functions have been investigated.[15] Considering the present intricate and changing tariff schedules for public communications, a true cost method yields better cost estimates for an actual network.

Network reliability is the ability of a network to continue to function in an acceptable manner after the loss

of one or more nodes or links. The number of nodes or links which may fail while still maintaining an acceptable level of network performance depends on the application.

Optimizing Network Performance

The design and analysis of a computer communication network involve many variables. The most significant design variables are topology, link capacity, node capacity, link protocol, routing procedure, precedence discipline and flow control.[5,6,12,15,18,27,28] Generally, the location of the host computers, the input traffic characteristics and the implementation costs are known. Optimum network performance is defined as achieving an acceptable level of message delay or throughput at minimum cost.

The design process is often partitioned into four optimization problems which differ only in the choice of design variables.[12,15,28] The four design cases are 1) link capacity assignment, 2) flow assignment, 3) capacity and flow assignment, and 4) topology, capacity and flow assignment. Since the large number of interrelated variables precludes an exhaustive search for the optimum design, a heuristic searching technique is used.

The search begins by selecting a starting topology. Flow and capacity assignments are made and the network performance and cost are determined. Slight modifications

are made to the network, and the network performance and cost are checked for improvement. The process is repeated until an acceptable network is found. The simulation model developed and implemented in this study is used to determine network performance at each iteration of the search.

A Classical Analytic Network Model

Kleinrock has developed an analytic model of a store-and-forward computer communication network which has been widely accepted.[12,15] He models a computer communication network as a system of single-server queues. This modeling approach has been applied to a variety of network situations using both analytic and simulation models.[8,9,19,25,30] In this section the analytic model is discussed, and the results for specific numerical examples using the model are reviewed.[12] These analytic results are applied in chapter III to validate the accuracy of a baseline computer simulation model.

Single-Server Queue Model

One unidirectional path through a switching computer at a network node is represented schematically in figure 3. Incoming messages are stored in a buffer queue until the outgoing transmission path, or server, is available. The total delay experienced by a message at the node consists primarily of the waiting time in the queue plus the

transmission time on the outgoing link. The most significant measure of steady-state performance for the node is given by the average delay experienced by a message passing through the node. Subject to certain assumptions, an analytic expression for average delay is well known.[15] The assumptions are introduced to simplify the mathematical model; thus, the model is an approximation of the characteristics of a real system.[12]

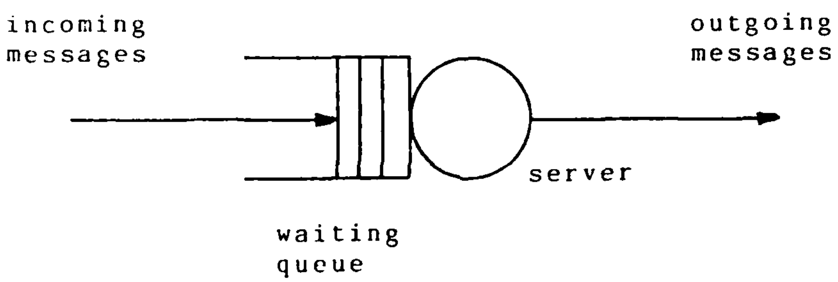


Figure 3: Single-Server queue.

The arrival of messages at the node is assumed to be a Poisson process with an average rate for message arrivals of λ messages/second. Message lengths have a negative exponential distribution with a mean of $1/\mu$ bits. The transmission speed of the outgoing link is C bits/second. For a message length of b bits the transmission time is b/C seconds. Messages are transmitted in order of arrival; that is, first-in-first-out (FIFO). Storage space for the queue is assumed infinite so that no message arrivals are

rejected. The values of λ and μ, which characterize the random distributions for message arrivals and message lengths, are constants. A fundamental result of queueing theory gives the average waiting time in the queue as

$$r = \frac{\rho}{\mu C(1-\rho)}$$

where $\rho = \lambda/\mu C$ is the utilization factor for the link. The total average delay in the system is the sum of the average waiting time and the average transmission time:

$$T = r + \frac{1}{\mu C} = \frac{1}{\mu C-\lambda}$$

Multiple Queue Model

Using the results for a single-server queue, Kleinrock extended the concept to an M-link N-node network. The computer communication network is modeled as a network of interconneced single-server queues. Figure 4 represents a segment of a network showing how the queues are interconnected. The input to a queue may come from more than one source. In constructing an analytic model for this network Kleinrock made some aditional assumptions beyond those stated previously.

The M-links are assumed to be error-free, computer processing time at each node is assumed negligible, and electrical propagation time between nodes is ignored. The

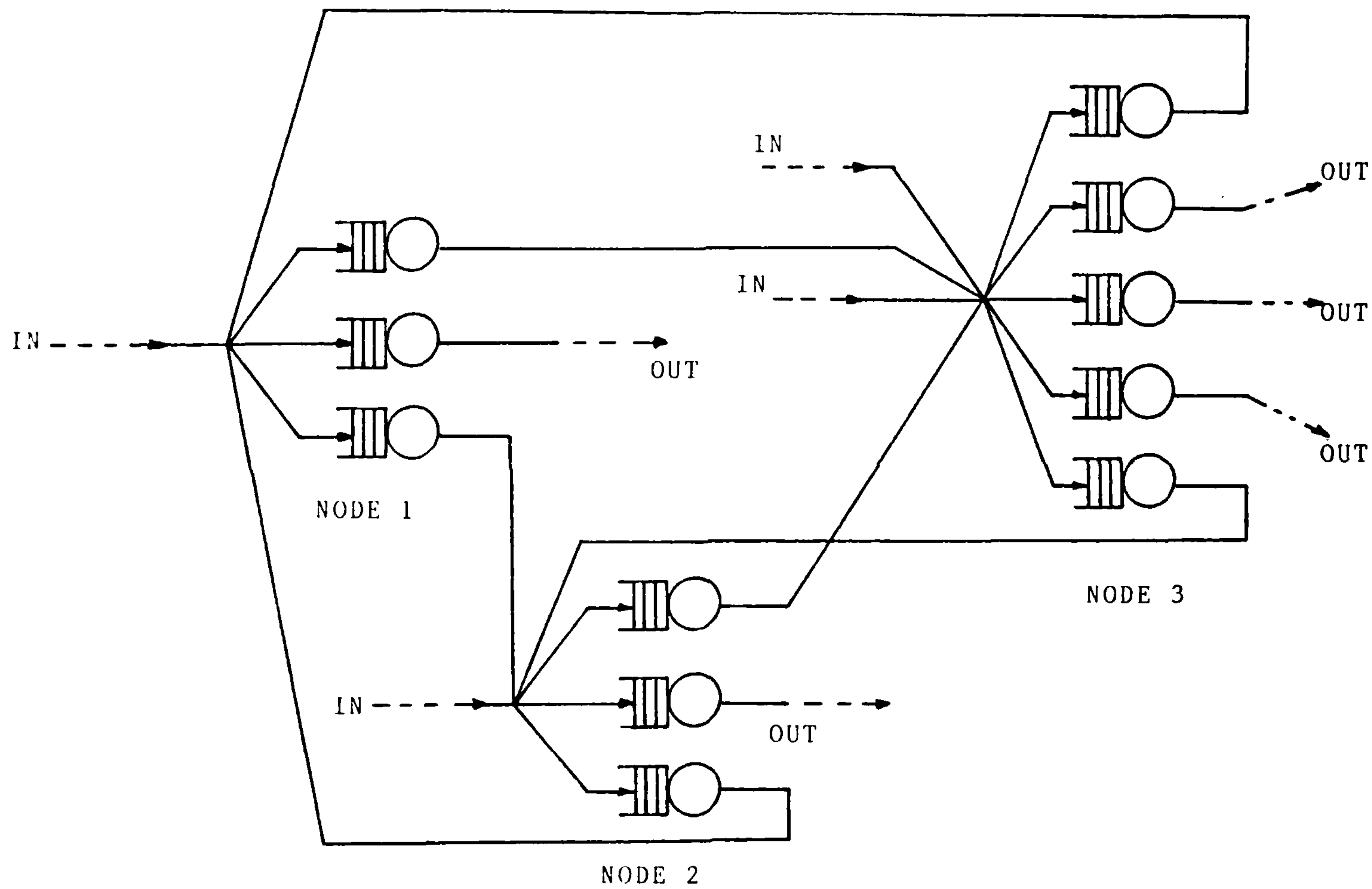


Figure 4: Multiple queue model of a computer communication network.

average message arrival rates are given by a traffic matrix in the form of table 1. The Gjk entries are the traffic intensities from source node j to destination node k given in messages/second. The total external traffic entering the net is

$$G = \sum_{j=1}^{N} \sum_{k=1}^{N} Gjk$$

TABLE 1

TRAFFIC MATRIX

node	1	2	3	...	k
1	-	12	13	...	1k
2	21	-	23	...	2k
3 . . . j	31 . . . j1	32 . . . j2	- . . . j3	... ...	3k . . . -

Message routing through the network is fixed. The average number of messages which travel over the ith link of capacity Ci is λi, and the average delay for the ith link is $Ti=1/(\mu Ci-\lambda i)$. To avoid severe mathematical difficulties, Kleinrock assumes that a new message length

is chosen from a random distribution at each node. This independence assumption is contrary to reality, but it does produce a simple model which gives reliable results.[12] Based on these assumptions, the average message delay for a network is

$$T = \sum_{i=1}^{M} \frac{\lambda i}{G} Ti \tag{1}$$

This expression for T, message delay averaged over the entire network, is a major performance measure for the network. The average message delay has a sharp threshold behavior as the rate of traffic input to the network is increased. The delay will rise sharply toward infinity whenever any single link in the network becomes saturated with messages. This occurs when message arrivals exceed the outgoing link transmission capacity.

Kleinrock also proposed a second analytic model in his original work.[12] In this model an average path length $\bar{n}$ is calculated based on an assumed fixed routing procedure. The average message delay T is

$$T = \frac{\bar{n}\left[\sum_{i=1}^{N} \sqrt{\lambda i/\lambda}\right]^2}{\mu C(1-\bar{n}\rho)} \tag{2}$$

This model also exhibits a sharp threshold behavior as the rate of traffic input to the network is increased. It does not, however, rise toward infinity when any single link becomes saturated. The message delay for the model becomes infinite as $\bar{n}\rho$ approaches unity. This model gives a more optimistic value for message delay and conceals the point where links in the real system become saturated.

Kleinrock's Numerical Examples

In this section two numerical examples published by Kleinrock are reviewed.[12] The results of these analytic models will be used to validate the computer simulation model developed in chapter III.

Star Network

A 5-node star network has a traffic matrix as defined in table 2. The total network capacity is given as C=38.33 bits/second and message length is given as $1/\mu=0.1$ bits. The individual link capacity assignments are shown in figure 5. Using the analytic equations (1) and (2), the average message delay is shown in figure 6.

TABLE 2

TRAFFIC MATRIX EXAMPLE

node	messages/second				
	1	2	3	4	5
1	-	9.340	0.935	2.940	0.610
2	9.340	-	0.820	2.400	0.628
3	0.935	0.820	-	0.608	0.131
4	2.940	2.400	0.608	-	0.753
5	0.610	0.628	0.131	0.753	-

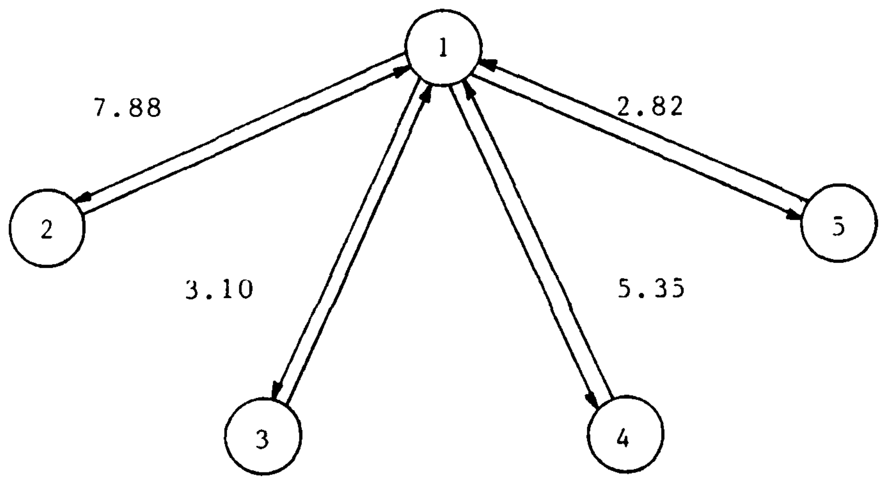


Figure 5: Kleinrock's star network example. Link capacities shown are in bits/second.

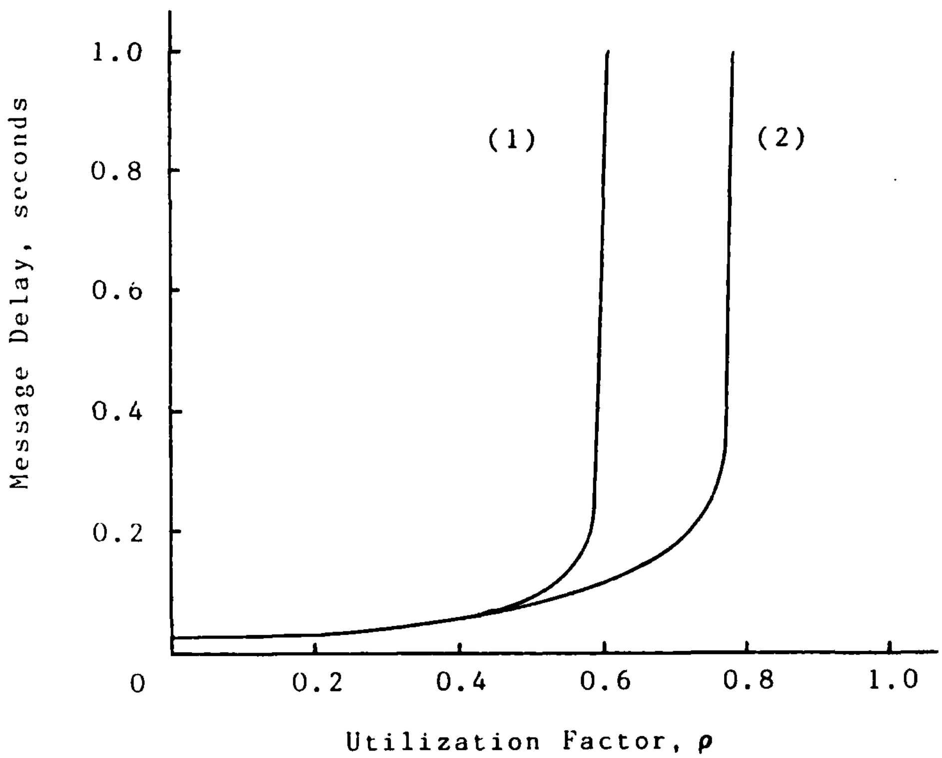


Figure 6: Message delay for star network example using analytic equations (1) and (2).

Fully-Connected Network

The 5-node fully-connected network in figure 7 has the same traffic matrix as defined in table 2. The total network capacity remains 38.33 bits/second. The average message delay for the fully-connected network calculated using analytic equations (1) and (2) is shown in figure 8.

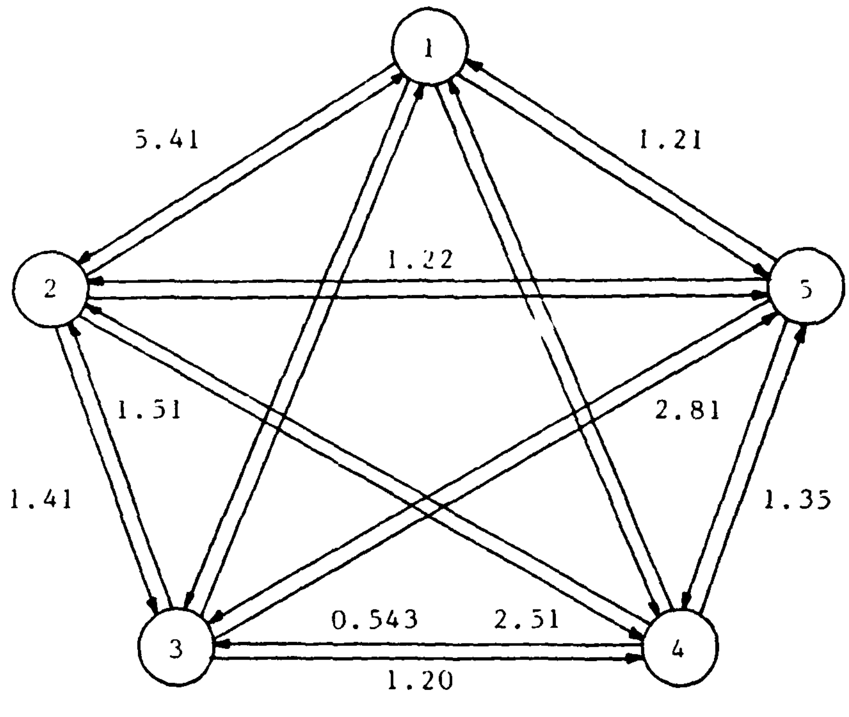


Figure 7: Kleinrock's fully-connected network example. Link capacities shown are in bits/second.

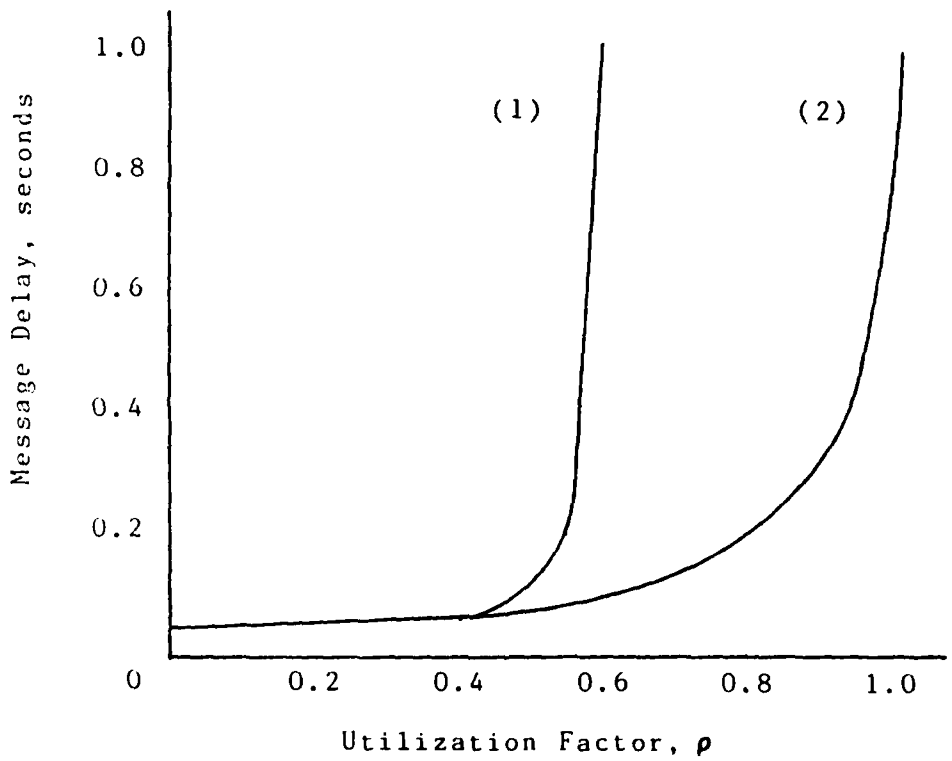


Figure 8: Message delay for fully-connected network example using analytic equations (1) and (2).

<u>Comments on Analytic Models</u>

Throughout the literature on analytic models of computer communication networks frequent mention is made of the intractability of mathematical solutions to these models.[5,15,19,25] Kleinrock states:

> It is not hard to convince oneself that queueing theory is rather difficult and that exact results are hard to obtain; in fact, <u>many</u> of the interesting queueing phenomena have not yet yielded to exact analysis (and perhaps never will!). Moreover, in those simpler systems where exact results can be obtained, their form is sometimes so complex as to render them ineffectual for practical applications.[15]

While it is not reasonable to suggest forgoing analytic solutions, the urgency of solving present day computer communication network design problems drives one toward simulation models. When choosing between full scale network experimentation and simulation modeling, the latter clearly costs less to accomplish.

The two analytic models described in this chapter represent very rudimentary network designs. Adding detail to the analytic model to evaluate realistic alternatives is a formidable problem; however, adding detail to the computer simulation model is a reasonable goal. The following chapters present the details of a computer communication network simulation model for estimating average message delay and message throughput.

CHAPTER III

THE SLAM SIMULATION MODEL

Introduction

A computer simulation model is developed and implemented to investigate the performance of computer communication networks. The resulting model is a logical, mathematical representation of network activity and is used to estimate network behavior under a variety of hypothetical conditions. The simulation is a discrete-event stochastic model. It is written using a modular approach. In this chapter the simulation program development is described. Next, the modules of a baseline simulation of a computer communication network are described, and Kleinrock's 5-node network is used to validate the baseline simulation.[12] Finally, the full computer communication network simulation is presented.

The SLAM Language

Simulation Language for Alternative Modeling (SLAM) is a FORTRAN-based language distributed by Pritsker and Associates, Inc. of West Lafayette, Indiana.[24] This language was selected because its process oriented statements are suitable for modeling a computer communi-

cation network. The brief overview of the SLAM network language in this section will assist in understanding the models presented in this chapter. A detailed example of a SLAM simulation model of a single-server queue is presented in appendix A. A complete tutorial of the SLAM language is found in references [23,24].

A SLAM simulation includes control statements and a network description. The control statements initiate, modify and terminate the simulation and provide a means for selecting among options in the SLAM language. The network description is the unique portion of the program which the modeler writes to represent a real world process.

In the SLAM network description entities (messages) flow through a process (store-and-forward communication network). An entity can be assigned attribute values (message length, origin, destination) which distinguish it from other entities. Groupings of entities are called files. A process consists of a collection of actions (transmit, receive, check for errors) and structures (memory, channels) which correspond to the operation and configuration of the communication network being modeled.

Using a set of SLAM graphic network symbols, the communication network model is constructed. The SLAM graphic symbols form a shorthand notation for describing a model; and the simulation program is written by translating the graphic symbols into SLAM language statements. The

graphic symbols are an effective means of communicating the operation of a model and of documenting the simulation. Plain language comments inserted into the listing together with a SLAM network diagram form a complete documentation package for the simulation. There are 23 SLAM network statements available for constructing models. This makes SLAM an effective simulation language.

The output from a SLAM simulation can include an echo report, trace report, error messages or SLAM summary report. The first three reports are useful for debugging and validation of the model. The SLAM summary report displays the statistical results of the simulation.

A SLAM summary report is printed at the end of each simulation run or at intervals selected by control statements. The report includes statistics on files, activities or variables within a model. The SLAM summary report is the primary output of results from the simulation.

Simulation Program Organization

A top-down modular approach is used to construct the computer communication network simulation model. Dividing the network into functional modules facilitates writing the simulation in a logical and controlled manner. This method assists the validation process since each module can be checked for correctness individually. The modular

simulation allows changing one portion of the model without affecting others, thus permitting flexible experimentation and use of the simulation. With a top-down modular approach simulation details can be added or omitted according to the degree of detail desired in the simulation.

Message flow in a computer communication network simulation is described as shown in figure 9. Messages are created, queued, and transmitted, and performance statistics are gathered. These processes are catagorized into four major simulation module types. Each module type is composed of a number of activities which correspond to the real world actions being simulated. A fifth module type, external effects, is included to provide additional flexibility in the simulation model. The activities included in each simulation module are shown in figure 10.

The SLAM simulation model is developed in two phases. First, a simulation model of a computer communication network was written using the same network description and assumptions as the Kleinrock star network analytic model presented in chapter II. This is done to validate a baseline SLAM simulation. The validated baseline simulation is used as a basis for all later simulations.

In the second phase additional details are added in a step-wise fashion to the baseline simulation, expanding to a full simulation model which includes all the details

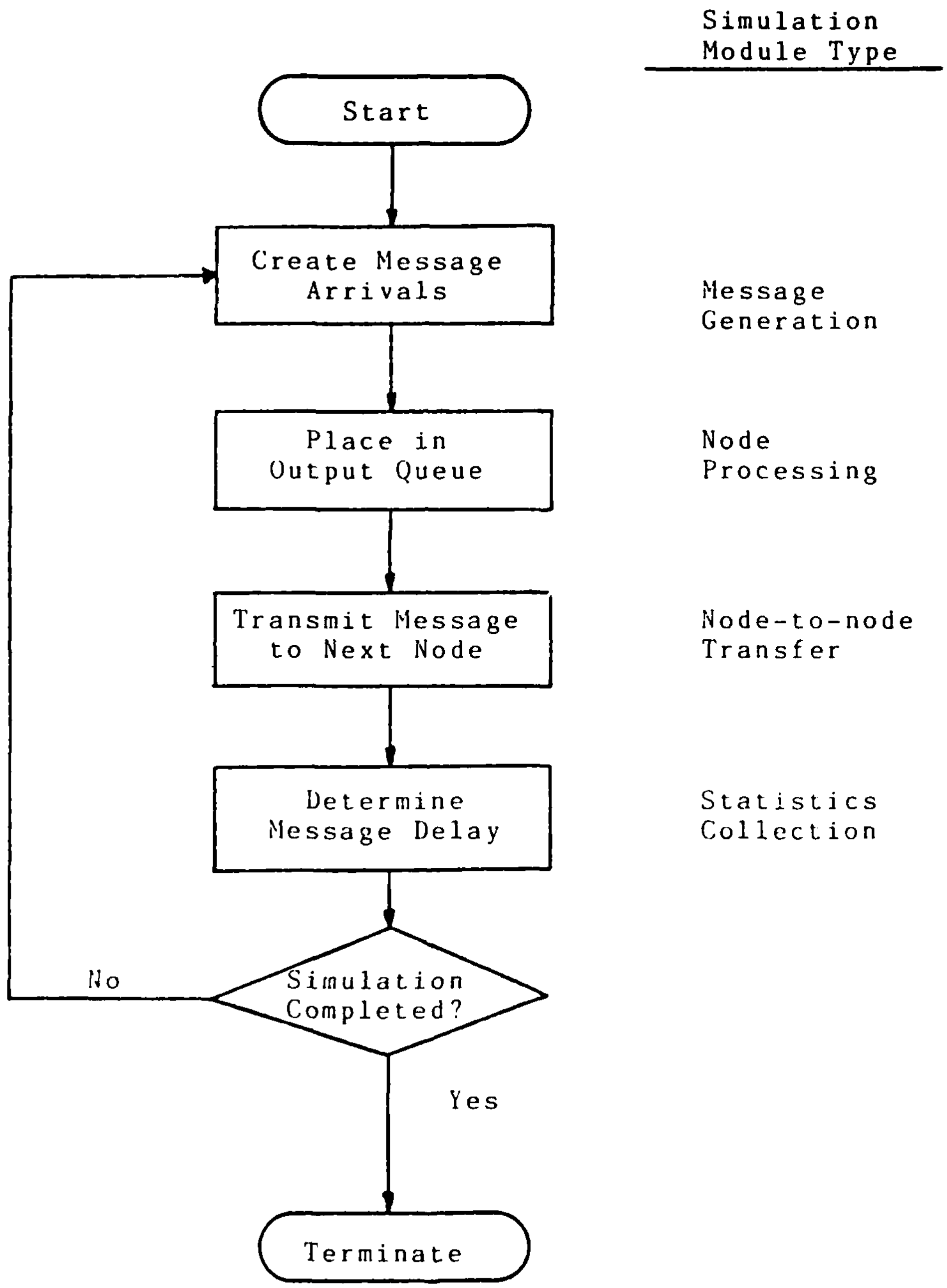


Figure 9: Message flow in a computer communication network simulation.

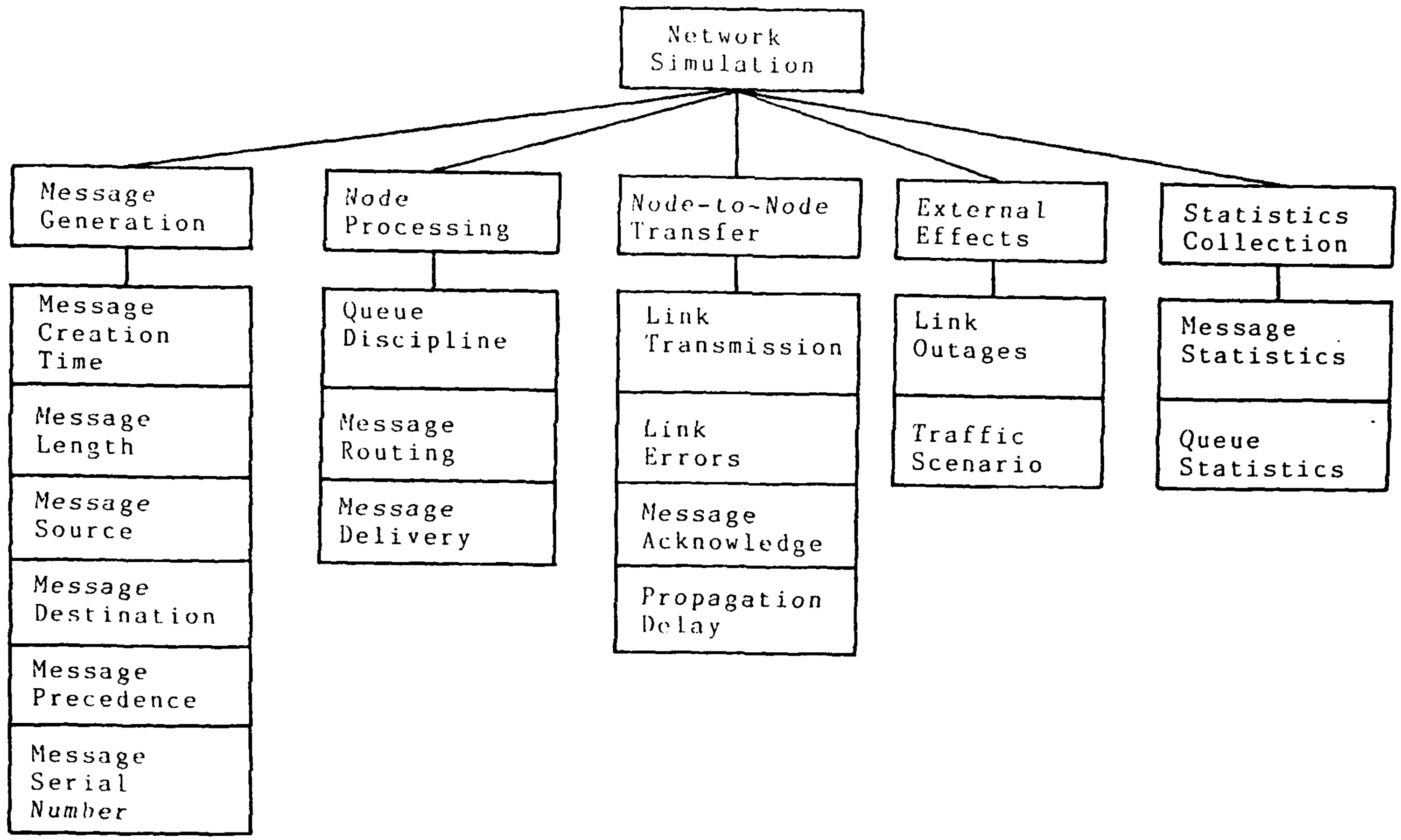


Figure 10: Modular structure of the simulation program.

shown in figure 10. The simulation is tested throughly at each step to insure that it produced consistent results. This procedure is used to insure the validity of the full simulation model. During the second phase, the full simulation model is used to analyze a hypothetical computer communication model.

Baseline Model

The baseline model for the star network is shown in figure 11 using SLAM network notation. The baseline model is used as the foundation to build and validate the full simulation model. The simulation is organized into four module types. SLAM language commands and labels are capitalized in this paper to permit easy reference to the network diagrams and program listings.

Message Generation Module

Message input to the network is specified using a traffic matrix as previously shown in table 1. Each Gjk entry in the matrix corresponds to a CREATE node having the time between creations selected from an exponential random distribution with a mean of 1/Gjk seconds. The traffic intensities were implemented as global variables XX(1) thru XX(10). Message attribute 1 contains the message creation time.

An ASSIGN node is used to place the destination node identifier into attribute 2. Traffic generated from

node 1, the central node in the star network, is placed in the appropriate outgoing queue according to the destination. Traffic generated from nodes 2 thru 5 is always transmitted to node 1 regardless of destination.

Node Processing Module

Node processing occurs only at the central node in this model. All other nodes can only send messages to the central node. At the central node each message destination, as indicated by attribute 2, is checked to determine message disposition. Messages terminating at the central node are sent to the statistics collection module represented by node TOT. All messages not terminating at node N1 are placed into the appropriate outgoing queue. Queue discipline is FIFO.

Node-to-Node Transfer Module

Transmitting a message is accomplished using a service ACTIVITY. The time for transmission on each link is $1/\mu Ci$. This value is used as the duration for each activity connecting the nodes in the network.

Statistics Collection Module

The time interval between message creation and message arrival at its destination is the message delay. This interval is determined at COLCT node TOT and reported in the SLAM summary report.

Baseline Model Validation

Repeated runs of the baseline model with varied traffic intensities are made to obtain a plot of average message delay against network utilization factor. The baseline SLAM simulation results are compared to

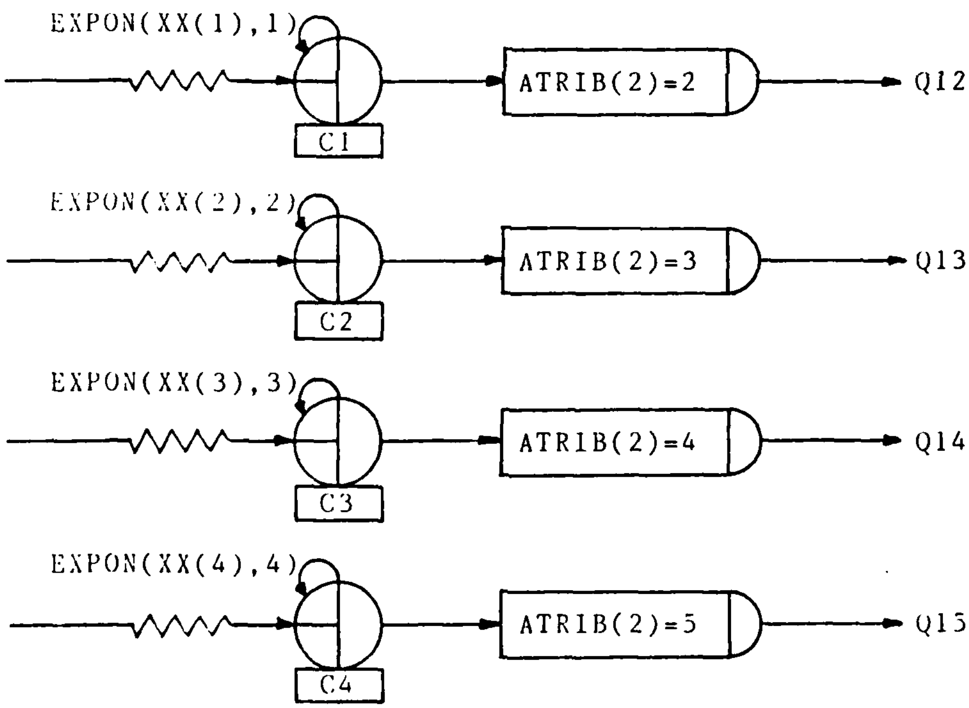


Figure 11: Baseline SLAM simulation network diagram, a) message generation module, node 1.

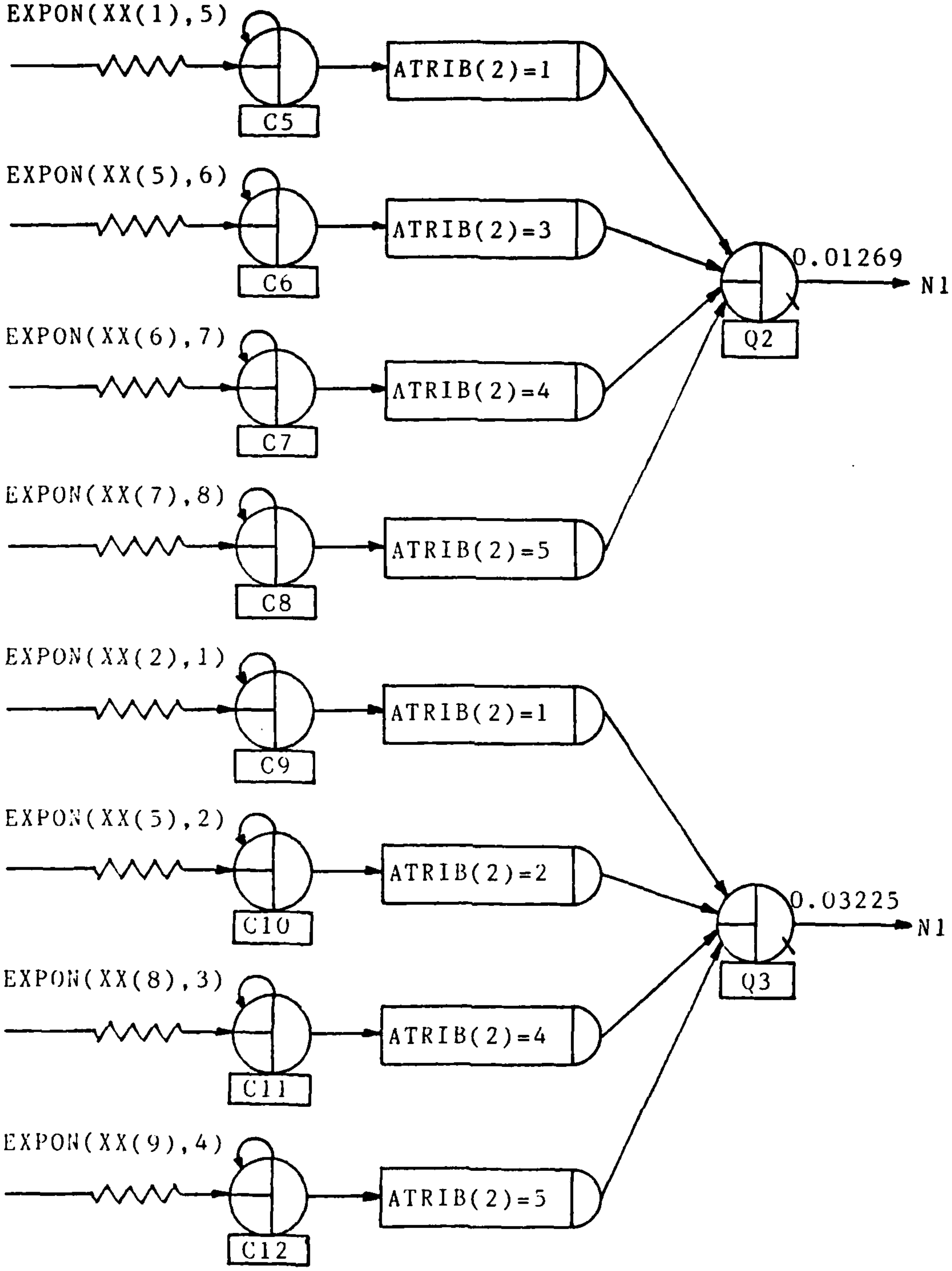


Figure 11 (con't): Baseline Slam simulation network diagram, b) message generation module and node transmission module for nodes 2 and 3.

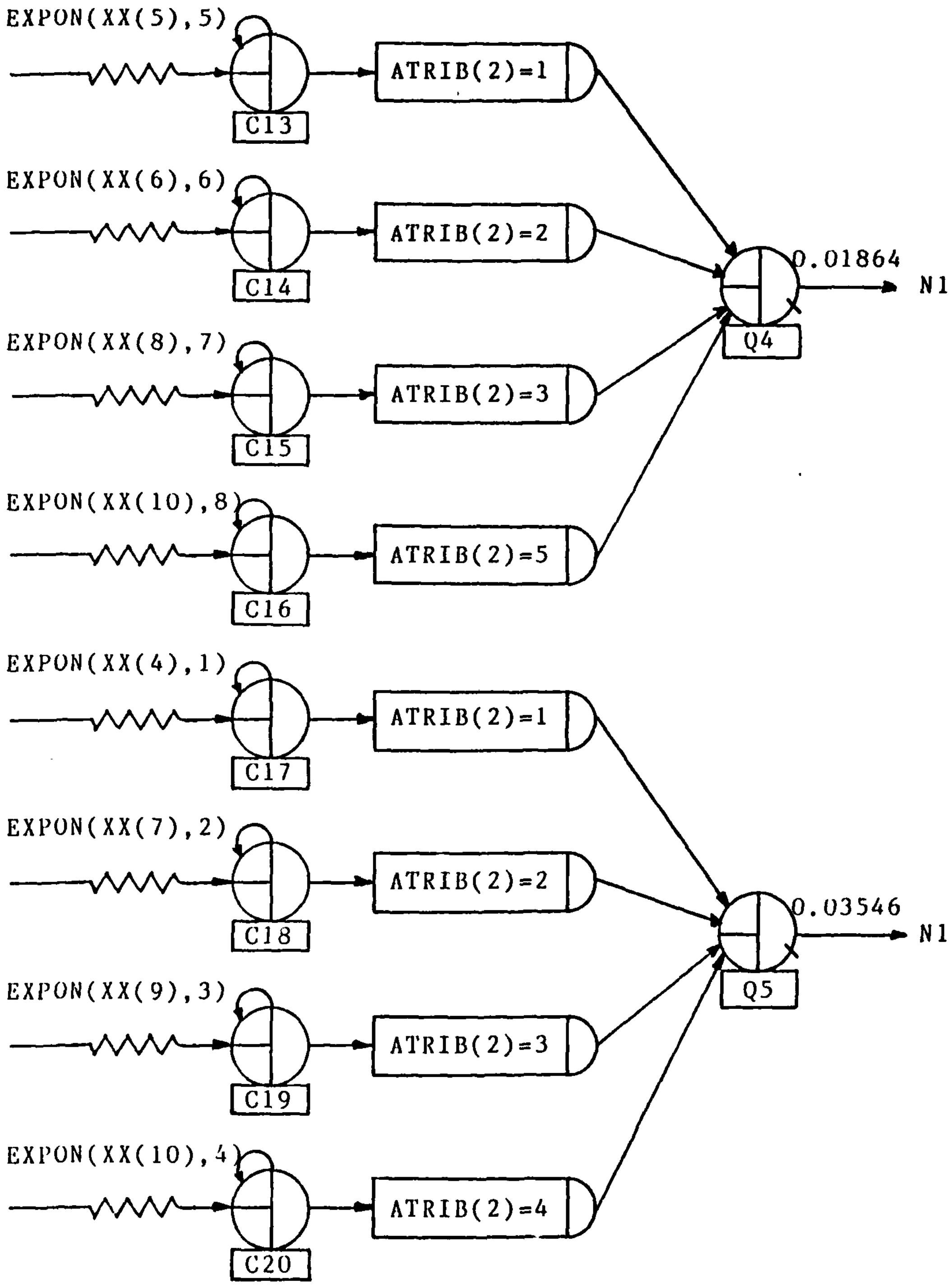


Figure 11 (con't): Baseline SLAM simulation network diagram, c) message generation module and node transmission module for nodes 4 and 5.

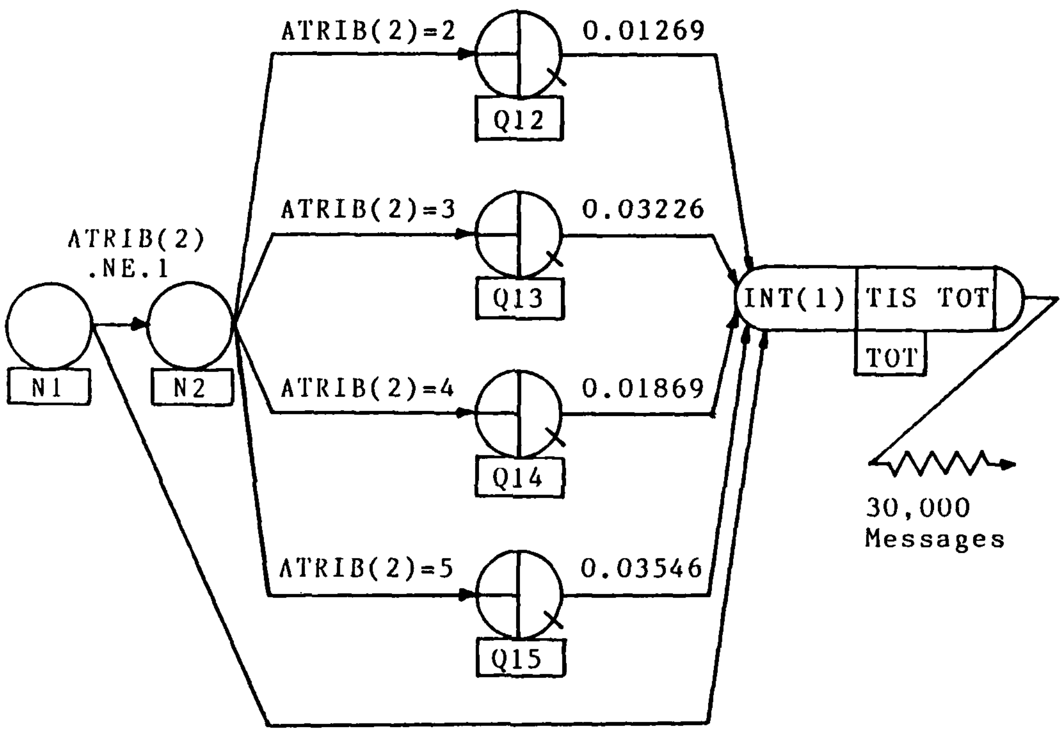


Figure 11 (con't): Baseline SLAM simulation network diagram, d) node processing, node-to-node transfer, and statistics collection modules.

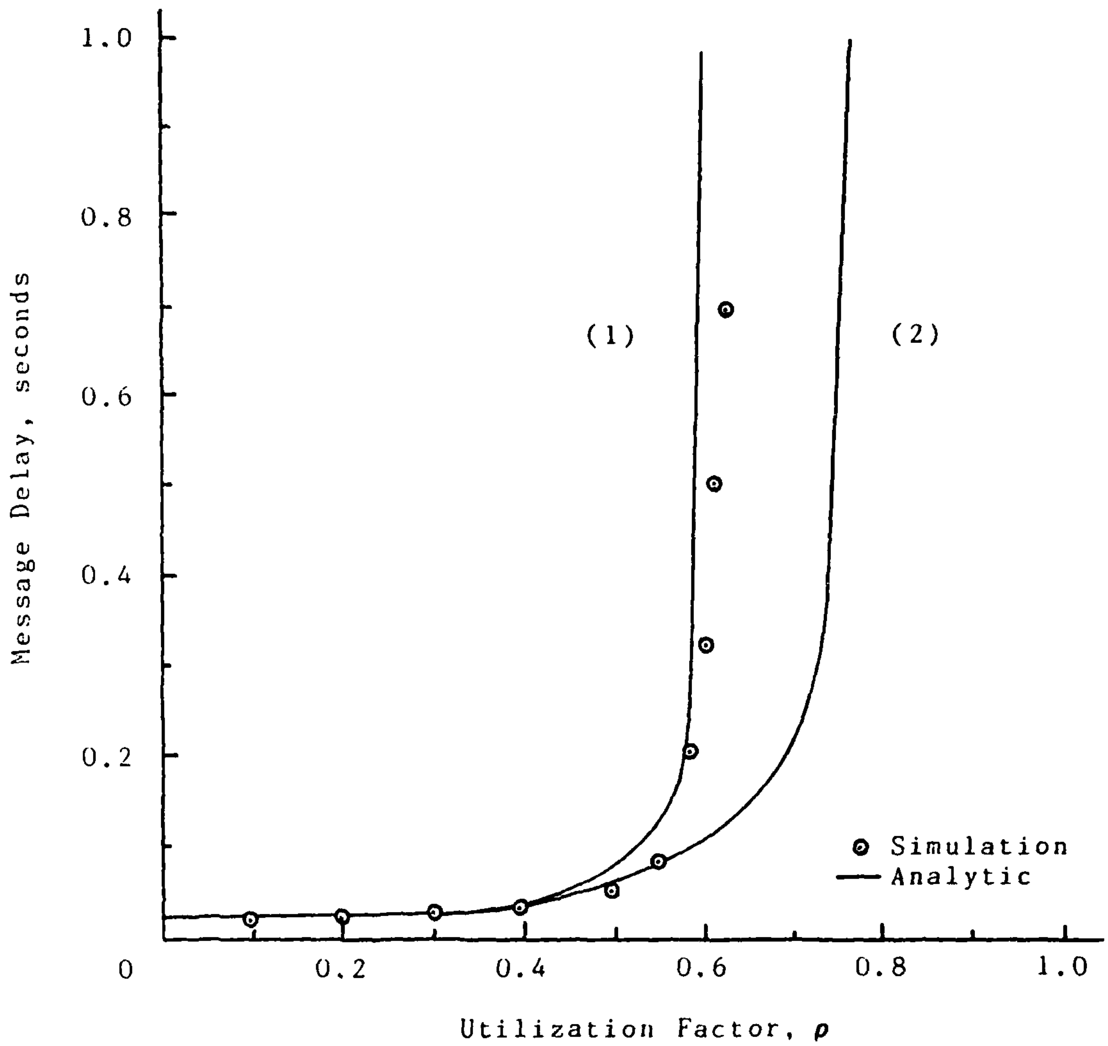


Figure 12: Baseline SLAM simulation compared with analytic equations (1) and (2).

Kleinrock's analytic model in figure 12. A sharp threshold behavior is strongly evident.

The SLAM trace report is used to verify the logical correctness of the SLAM program. The flow of messages through the simulation is checked by hand against the trace report output and verified correct. This provides a high degree of confidence that the simulation reproduces the desired model.

To verify that the simulation has reached a steady-state condition prior to computing the performance statistics, the following procedure is used. The simulation is run at 6 different rates of traffic input to transmit 20,000 messages. During each run a SLAM summary report is printed at intervals of 2,000 messages. The statistical arrays are cleared after each report. This provided a series of snapshots in time from the simulation. At each traffic input rate the message delays for each snapshot are approximately equal indicating an equilibrium condition. Queue lengths in the summary report are essentially constant for each snapshot. If the simulation is not at steady-state, the average message delay and the queue lengths increase with time.

Baseline Model Expansion

The baseline SLAM simulation of the star network is expanded to model a fully-connected network. This is done

by replacing all node processing modules with new modules similiar to figur 3. This module implements the fully-connected routing scheme and provides an outgoing queue for each link in the network.

The traffic intensities are varied to obtain a plot of average message delay against network utilization factor. The results of this simulation are compared to Kleinrock's analytic models in figure 14. The simulation results compare well to analytic model equation (1).

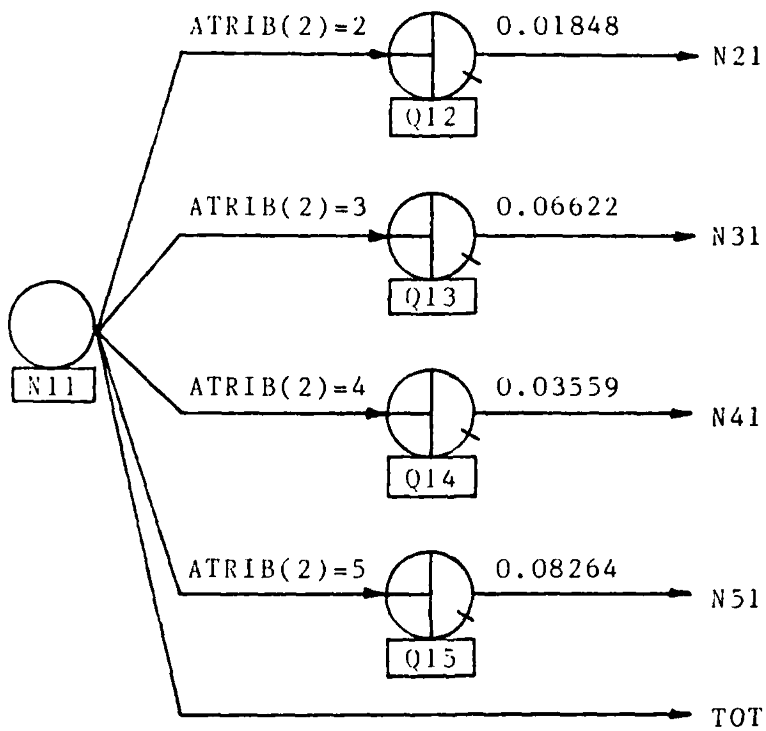


Figure 13: Fully-Connected SLAM network diagram, node processing and node-to-node transfer modules.

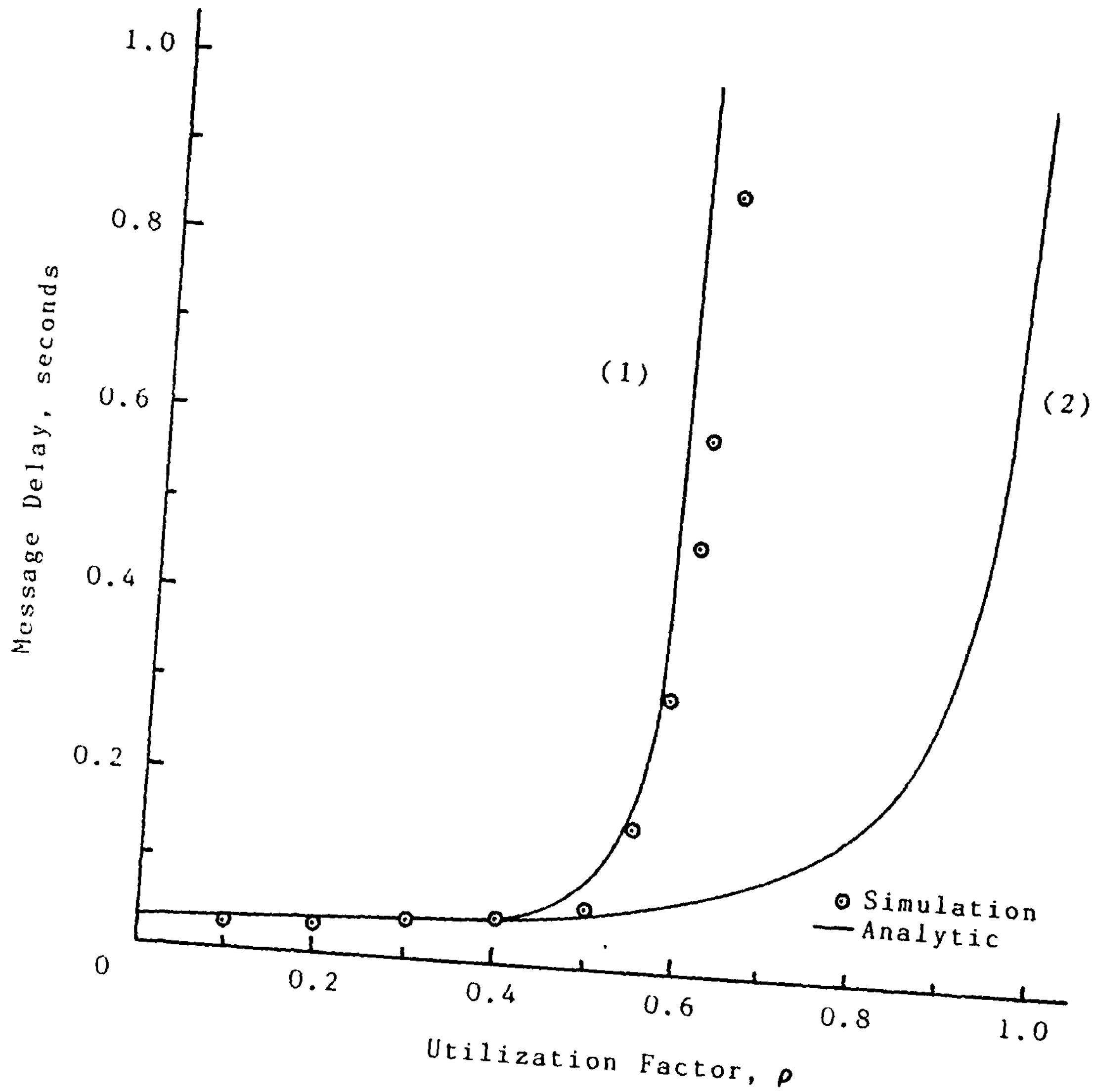


Figure 14: Fully-Connected SLAM simulation compared with analytic equations (1) and (2).

Comparing the simulation results for the star network with the fully-connected network shows that adding 6 additional links to the star network does not make a significant improvement in overall performance. The message traffic and link capacity between nodes 1 and 2 are the primary factors affecting average message delay. The simulation results show that this link is the first to saturate with increasing message flow. The fixed routing scheme does not take any advantage of the additional paths provided by the fully-connected network.

Full Simulation Model

The validated baseline simulation is expanded to include all the activities shown in figure 10. Each module is described in this section. A complete program listing and sample output is in appendix B.

Messsage Generation Module

All messages in the network contain the attributes listed in table 3. For each entry in the traffic matrix a module segment like that shown in figure 15 is required. This module segment randomly generates messages at the specified traffic intensity, marks all message attributes according to the probability distributions defined in the simulation control statements and places the messages in the appropriate outgoing queue. In an N-node network there are N(N-1) of these message generation module segments.

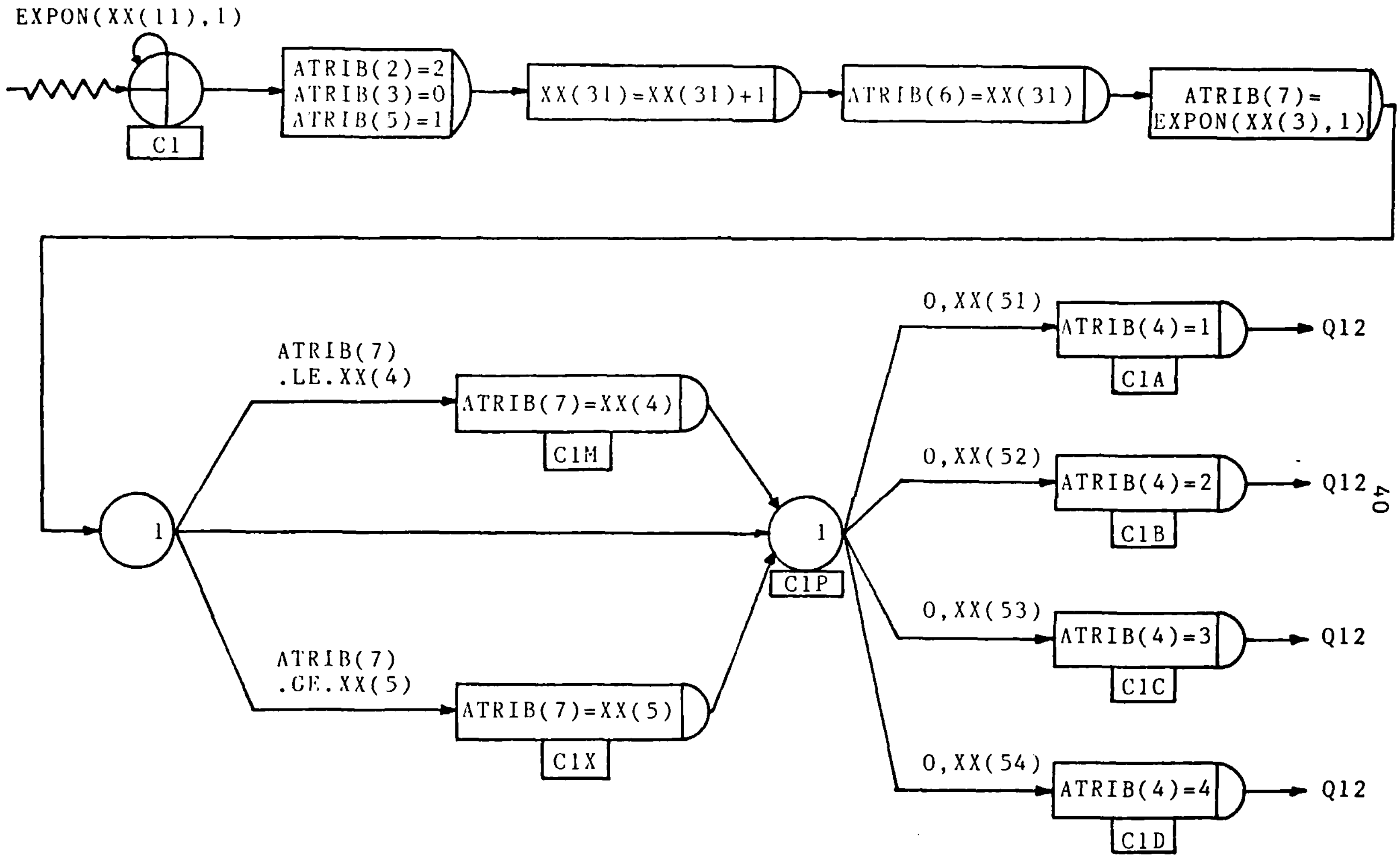


Figure 15: Message generation module segment for node 1 to node 2 traffic.

TABLE 3

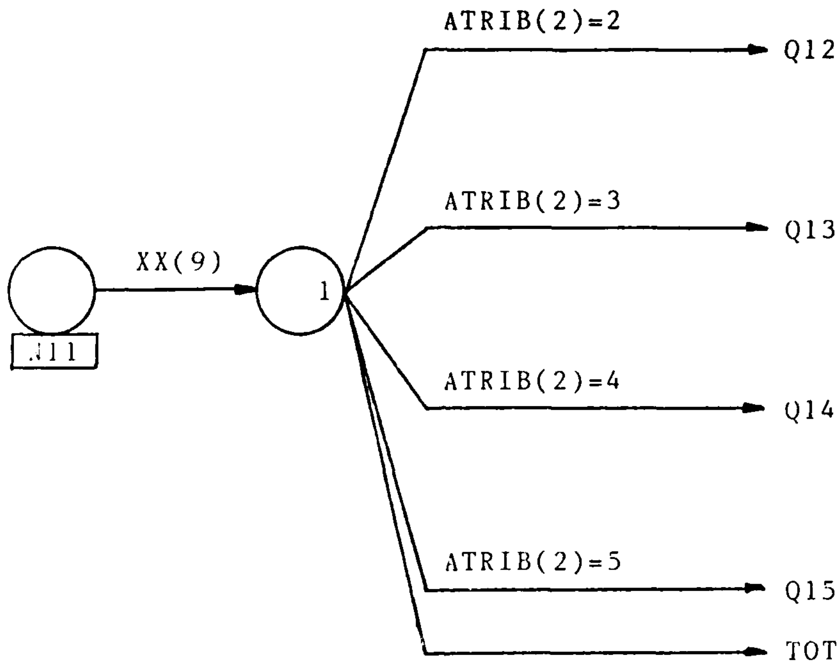
MESSAGE ATTRIBUTE DEFINITIONS

Attribute	Definition	Units
1	Creation time	seconds
2	Destination node	integer
3	Type	integer
4	Precedence	integer
5	Origin node	integer
6	Serial Number	integer
7	Length	bits

The message type attribute is used to distinguish original messages from response messages. A 4-level precedence scheme is used. The serial number attribute is used to provide each message with a unique identification marking.

Node Processing Module

At each node in the computer communication network a switching computer performs node processing tasks. In the simulation these activities are modeled as shown in figure 16. One module segment like figure 16 is required for each network node.



RESOURCE

LINK12	1
LINK13	1
.	.
.	.
.	.
LINKxy	r

PRIORITY

LVF	ATRIB(4)

Figure 16: Node processing module segment for node 1.

Not all of the node processing details can be included in this module due to the characteristics of the SLAM language. Control statements outside of the SLAM network description as well as an initialization module are required to accomplish the node processing activities.

A decision is made concerning the degree of detail of the node processing tasks to be modeled. Kleinrock assumed that node processing time is negligible.[12] This assumption is only valid for long messages or low link capacities. As link capacity increases and as node processing tasks increase in complexity, the computer processing time at a node cannot be ignored. No switching computer hardware specifications are assumed in this model; thus, the node processing overhead time is lumped into a single variable at each node.

All messages arriving to a node are sorted by destination. Messages that have arrived at their destination are sent to the statistics collection module.

Queue discipline is implemented using a SLAM PRIORITY control statement. The queue discipline is highest-precedence-first based on message attribute 4.

Fixed message routing is implemented in the simulation using node lables at the time the simulation is written. Messages are placed in an outgoing queue according to a routing table that depends on the network topology.

The network topology is defined at the beginning of the network description using RESOURCE statements. One RESOURCE statement is required for each communication link in the network, and it is initially defined with a value of zero. At the start of the simulation each link is ALTERed to the required network connectivity based on global variables indicating the number of lines per link.

Node-to-Node Transfer Module

Node-to-node transfer activities include simulating link transmission time, link errors and a message acknowledgement protocol. An ACK/NAK data link protocol is simulated.[6] Figure 17 shows a node-to-node transfer module segment for link 12. One module segment is required for each link in the network.

Link transmission errors are simulated using probability branching. The error rate is specified for each link using a global variable.

Messages are queued for transmission on the outgoing link at an AWAIT node. If the queue capacity is exceeded, messages overflow to the statistics collection module. When the link is available, the highest precedence message is transmitted with or without errors as determined by the link error rate. Messages free of errors are acknowledged (ACK), and the link is released to allow the next message to be transmitted. Messages with errors are negative

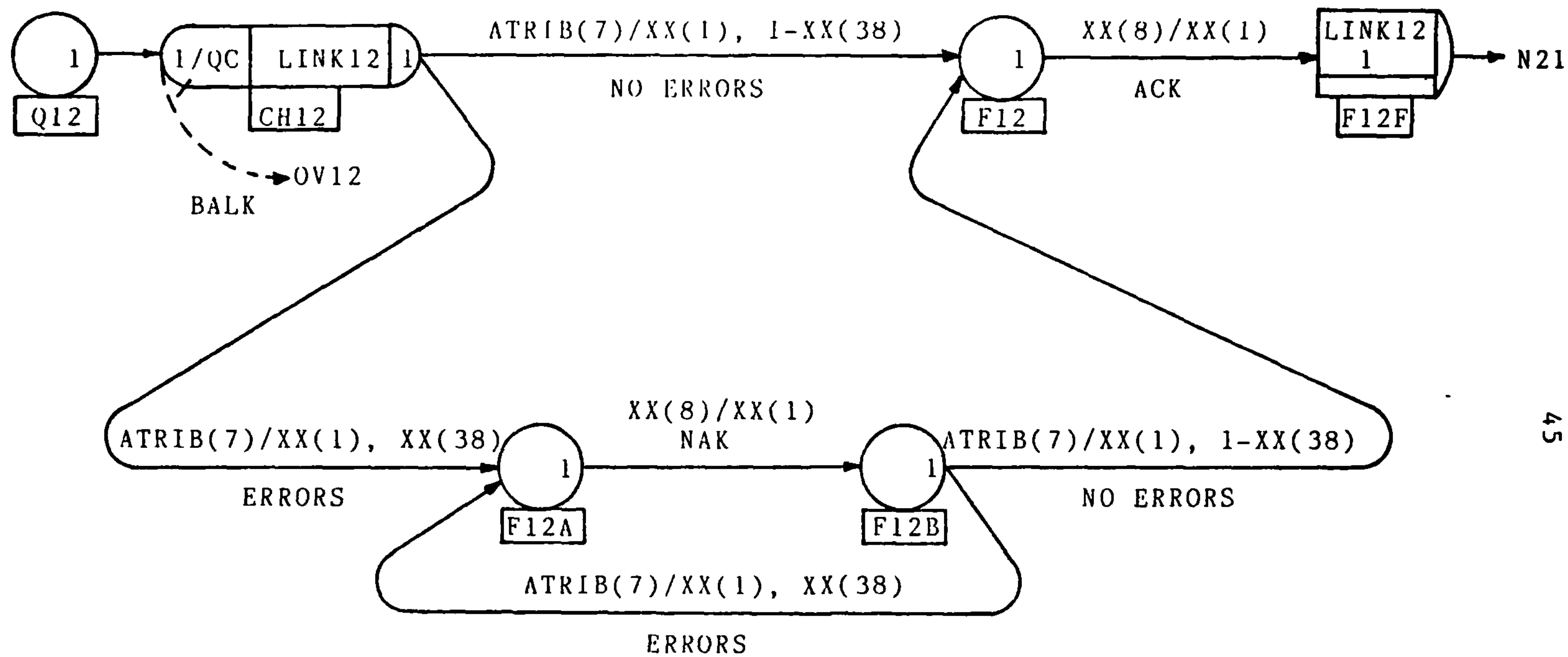


Figure 17: Node-to-Node transfer module segment for LINK12.

acknowledged (NAK) and retransmitted until they are received at the next node without errors.

The duration of the service ACTIVITY representing link transmission time is calculated for each message using the link capacity and message length.

Statistics Collection Module

The SLAM summary report provides all the statistical output information for the simulation. A SLAM COLCT node is used to collect statistics that are related to the time a message arrives at the node or on a variable at the message arrival time. Estimates of the mean and standard deviation are computed for each COLCT node.

The average length, maximum length and the average waiting time for each queue are computed. The average utilization factor for each communication link is computed.

The statistics collection module is shown in figure 18. Message delay is determined for all messages. After sorting on precedence the message delay is determined for each precedence level. All messages which overflow the queues are sent to a separate COLCT node for each queue.

External Effects Module

The external effects module is the portion of the simulation used to model events external to the computer communication network. The external effect module included in the full simulation model is shown in figure 19. This

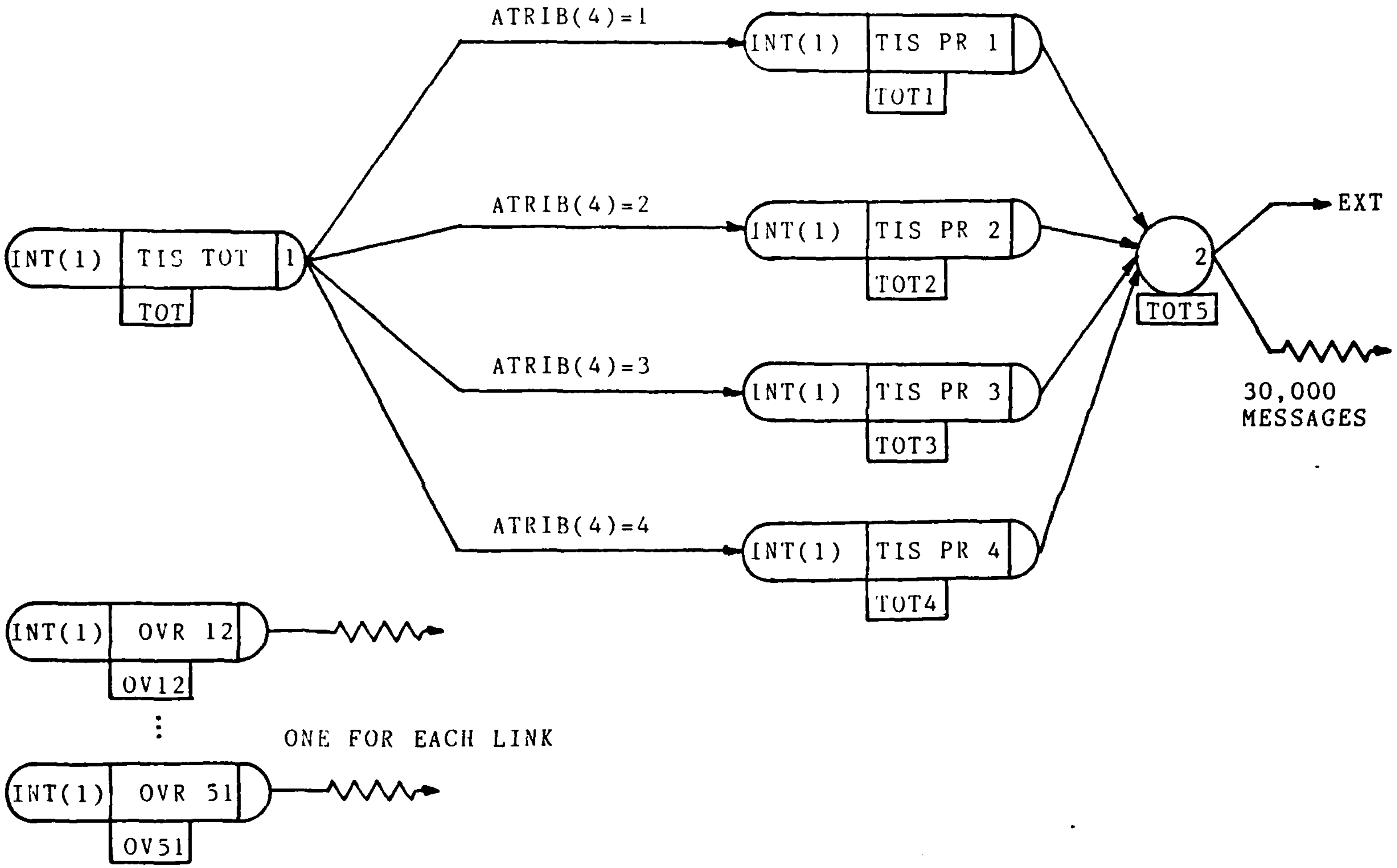
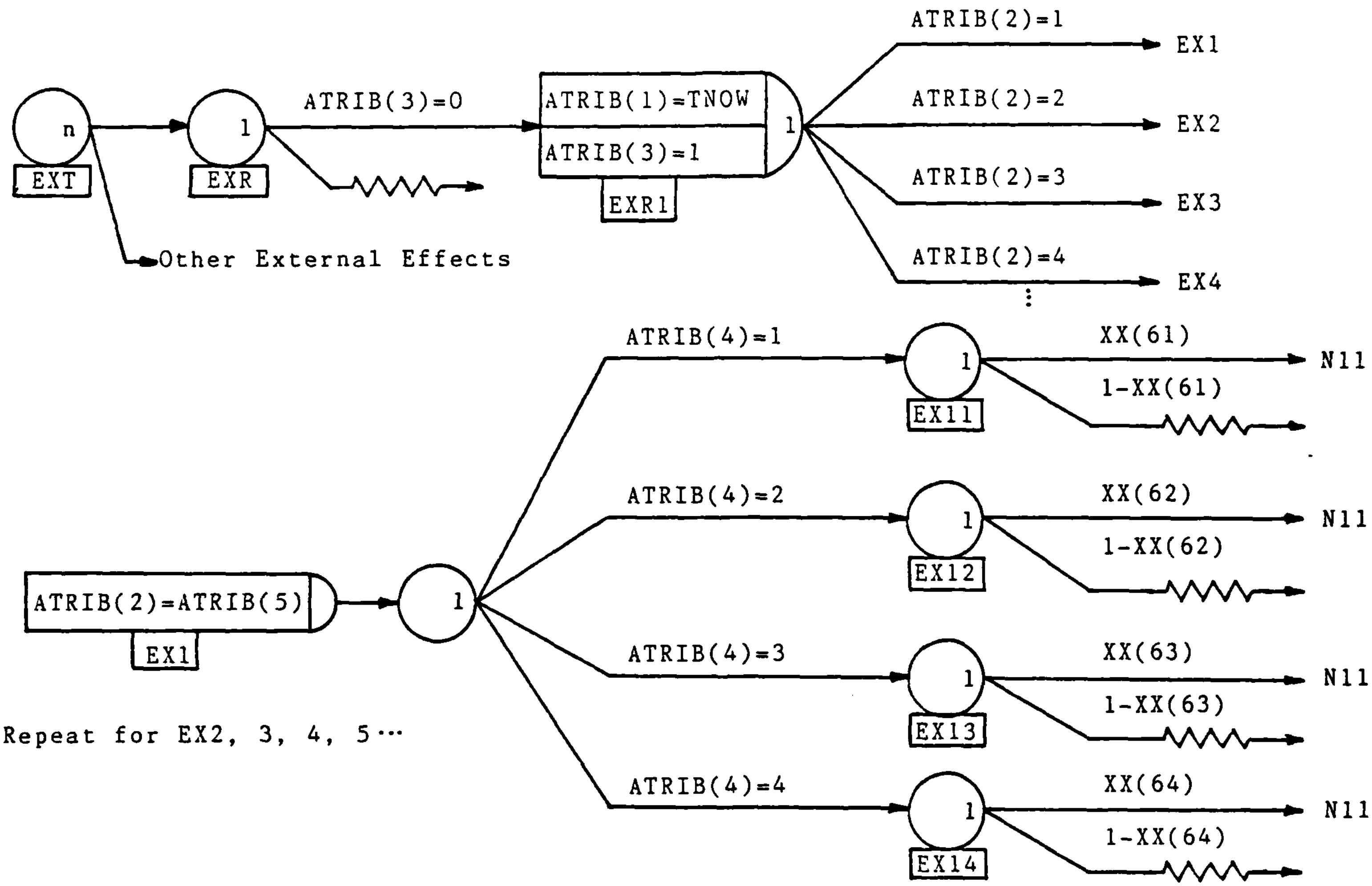


Figure 18: Statistics collection module segment.



Repeat for EX2, 3, 4, 5···

Figure 19: External effects module segment for response traffic.

module generates response messages when original messages arrive at their destination. The amount of response messages generated depends on the precedence of the arriving messages and on a response probability factor. Higher precedence messages generate more responses than lower precedence messages. Global variables are used as the response probability factors. The factors can be changed to observe the effect on network performance.

Messages are first sorted by type. Only original messages are used to construct a response message. The original message arrival time is used as the response message creation time. Messages are sorted by original destination so that the response message is sent back to the origin node. The response messages are then sorted by precedence. The response probability for each precedence level is used to determine if the response message is transmitted or discarded. The module segment in figure 19 is repeated for each node in the network.

CHAPTER IV

PERFORMANCE EVALUATION OF A NETWORK

Introduction

To apply the SLAM simulation model and demonstrate the method of optimizing network performance, a hypothetical 5-node network is assumed. First, the selection of topology and assignment of link capacities are addressed. The baseline simulation is used to determine average message delay for a series of progressively more costly network alternatives. One alternative network is selected, and the full simulation model is used to investigate network performance. Each simulation detail included in the full model is varied to demonstrate the effect on network performance.

Network Description

The minimum connectivity requirement for the hypothetical network is shown in figure 20a. Each one-way link has a capacity of 2400 bits/second, and additional capacity may be added only in increments of 2400 bits/second. Average message lengths are equivalent to one-half of a common video screen display in ASCII code or 6400 bits. A minimum message length of 100 bits and

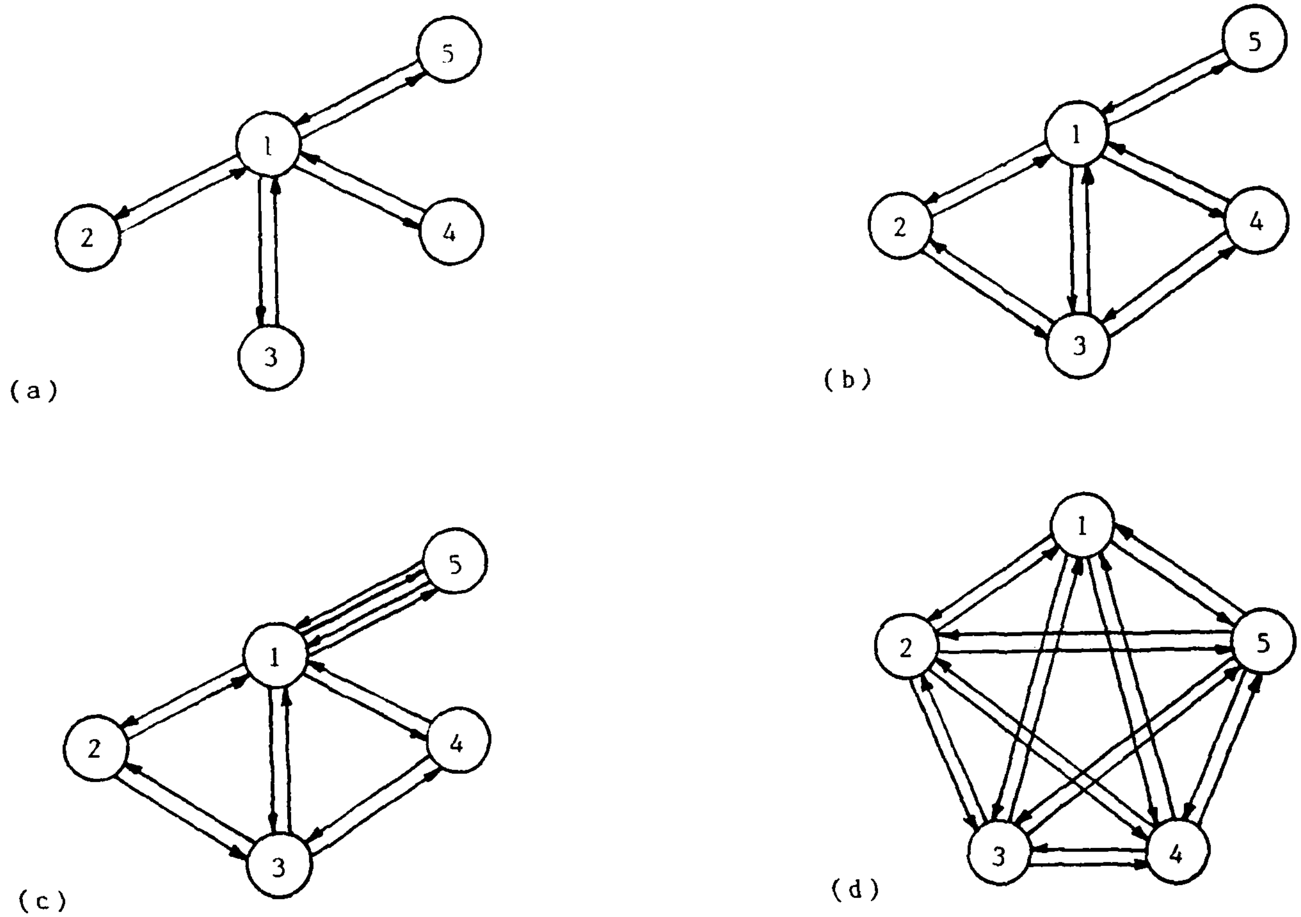


Figure 20: Simulation network topologies, a) star, b) mesh, c) mesh-plus, d) fully-connected.

maximum of 25,600 bits is imposed to confine the traffic input to realistic values. Traffic input to the network is evenly distributed over all nodes and destinations for this analysis, but the simulation can accommodate any distribution of traffic among the nodes. A 4-level precedence system can be activated. An ACK/NAK node-to-node protocol with a selectable link error rate can be be activated, and response traffic may be introduced into the network.

Beginning with the star topology of figure 20a, network connectivity is increased to the mesh configuration of figure 20b, the mesh-plus configuration of figure 20c and the fully-connected network of figure 20d. The average message delay for each topology and link capacity assignment is estimated using the simulation model.

Star Network Performance

The message delay performance for the star network is plotted in figure 21. A sharp threshold behavior is evident.

The length of simulated time at low traffic input rates is approximately 11 hours, and the simulated time is approximately 1 hour at the highest rate of traffic input. The number of messages transmitted is 30,000. This is well in excess of the time required for the simulation to come to steady-state and was selected as a good compromise

between real simulation run time, computational accuracy and simulation file capacity.

Mesh Network Performance

The network topology is changed by adding two additional links between nodes 2, 3 and 4 to form the mesh network shown in figure 20b. A shortest path message routing scheme is used. The simulation results are shown in figure 21. Message delay is reduced in comparison with the star network. The value of improvement to the user is evaluated by considering the cost of adding the additional links. At low traffic intensities the improvement is negligible, but at traffic intensities above 100 messages/minute the delay is roughly halved by adding the additional links.

Mesh-Plus Network Performance

The links 1-5 and 5-1 are expected to be the primary factors limiting the mesh network performance since node 5 has only a single connection to the network. The simulation results show this to be true. At high traffic intensities the queue lengths for these 2 links are 10 times longer than for the other queues. Assuming that node 5 can only be connected to node 1, message delay performance can only be improved by increasing the link capacity. The link capacities between nodes 1 and 5 are doubled to form the next alternative network shown in

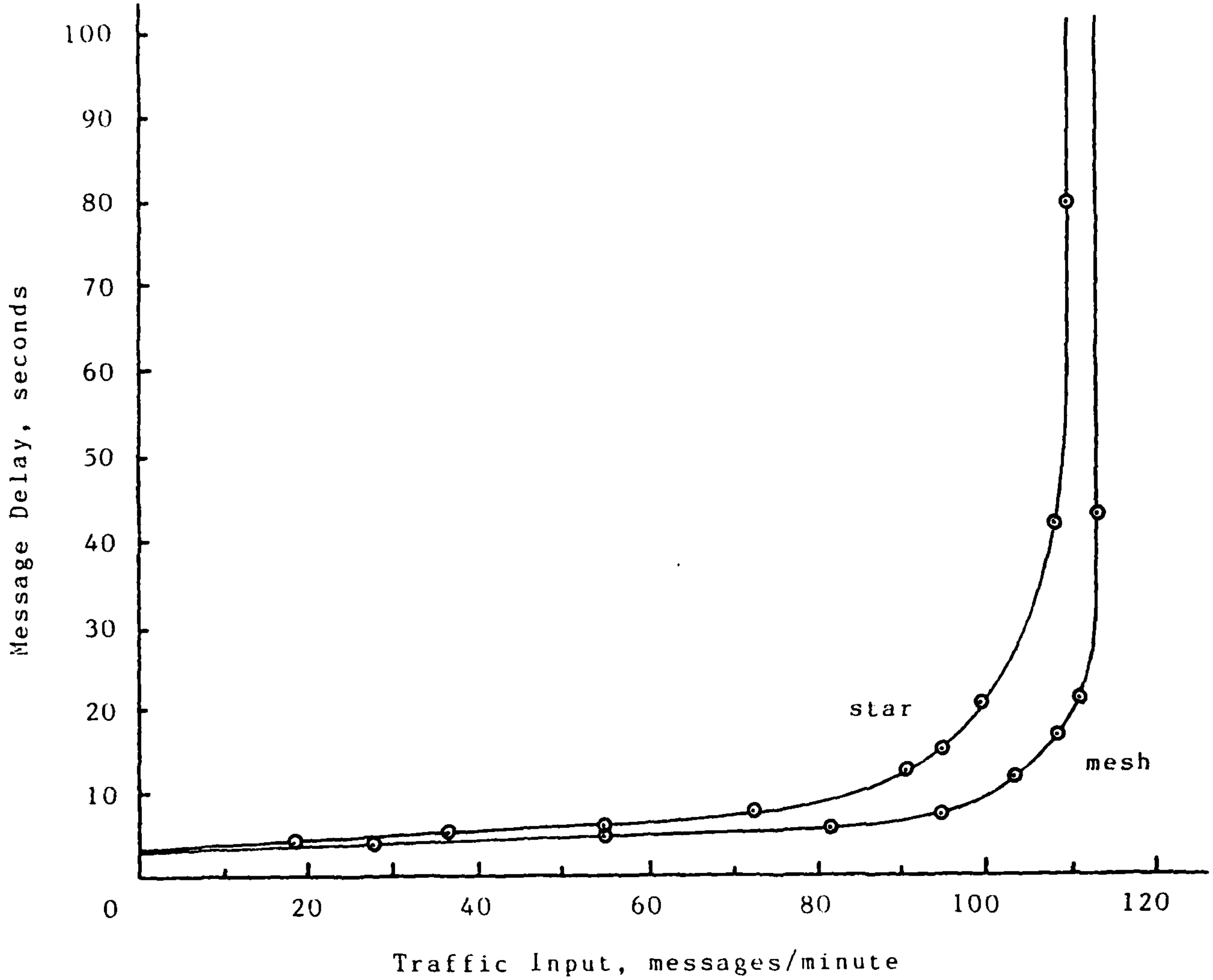


Figure 21: Message delay for star and mesh networks.

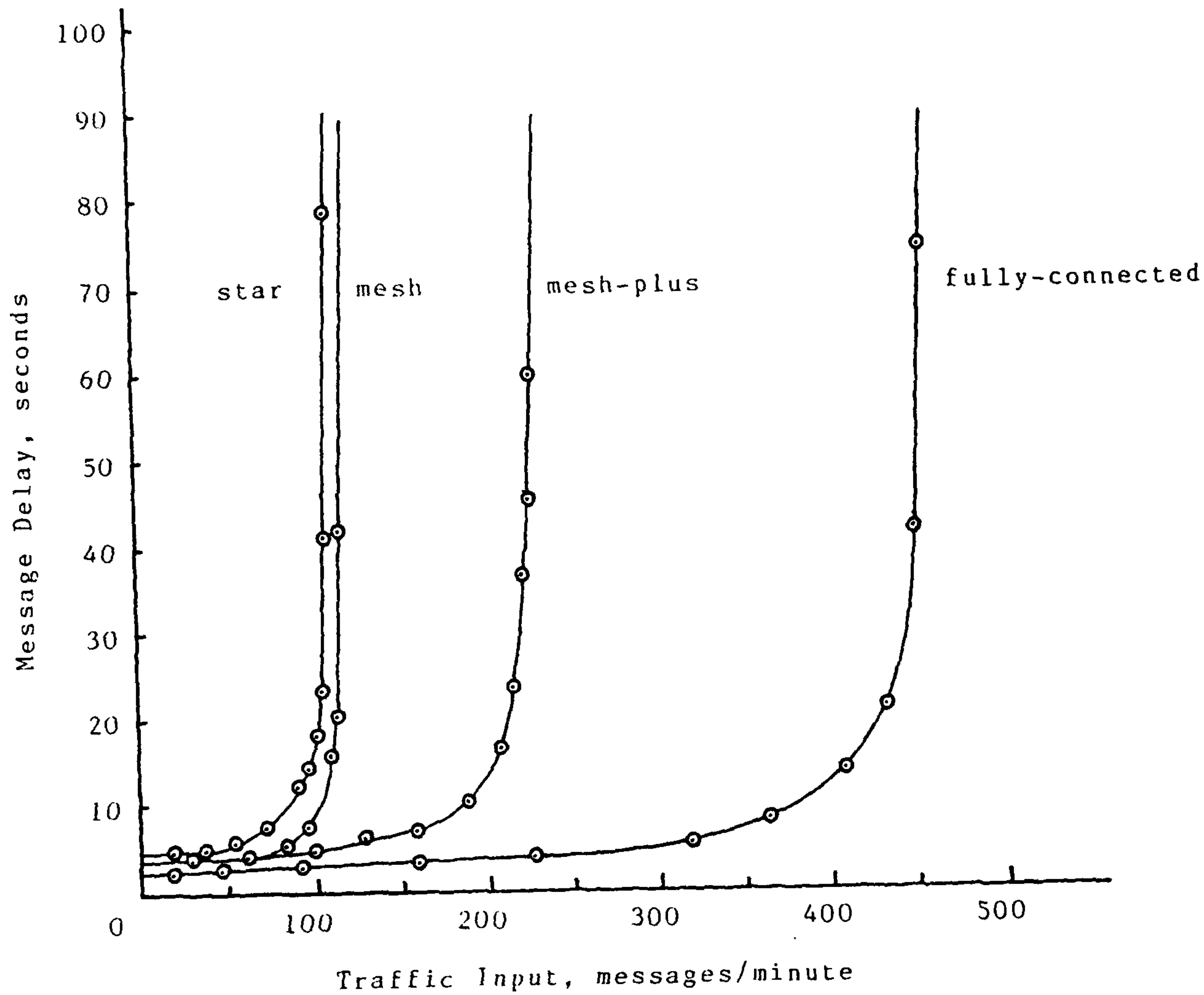


Figure 22: Message delay for network configurations.

figure 20c. As expected, average message delay performance is improved as shown by the curve labeled mesh-plus in figure 22.

Fully-Connected Network

Finally, the fully-connected network of figure 20d is simulated. This network has the maximum single link connectivity possible. The average delay performance curve, shown in figure 22, has the lowest delay of the 4 networks simulated. Other network topologies can also be simulated. The performance curves for other networks lie between the curves for the star network and the fully-connected network, assuming only single link capacity assignments. Improvement in performance over the fully-connected network requires increasing the single link capacities.

Optimum Network Selection

As the connectivity and link capacities are increased from the star network to the fully-connected network, the message delay performance improves, but the cost of building the networks also increases. By plotting network cost against message delay or message throughput, an indication of possible trade-offs are seen. For the purpose of presenting a hypothetical cost curve an assumption is made that each link costs 1 unit and that each additional line on a link costs 0.1 units.

In figure 23 message delay is compared with the cost of implementing the 4 alternative networks. For this example the throughput requirement is held constant at 12 Kbits/second (113 messages/second). The message delay for each alternative network is plotted with its cost. A dashed trend line connects the points for each network to aid in visualizing the cost/delay trade-off. The shape of the trend line reflects the relationship between the cost of adding link capacity and the resulting change in message delay. The pronounced discontinuity at the mesh-plus point occurs because of the large cost of adding additional links to form a fully-connected network. The added capacity does not significantly reduce message delay at the stated throughput requirement of 12 Kbits/second. From this limited set of alternatives the mesh-plus network is considered most cost effective in reducing system delay. A follow-on analysis of network cost proceeds with increasing the lines per link and finding the new network cost. This procedure continues until the time or budget for the analysis is exhausted.

Similarly, throughput performance is compared with network cost as shown in figure 24. The throughput values shown are for an average message delay of 5.2 seconds. The trend line again helps visualize the cost/throughput trade-off. The mesh-plus network appears to provide the best compromise between cost and throughput.

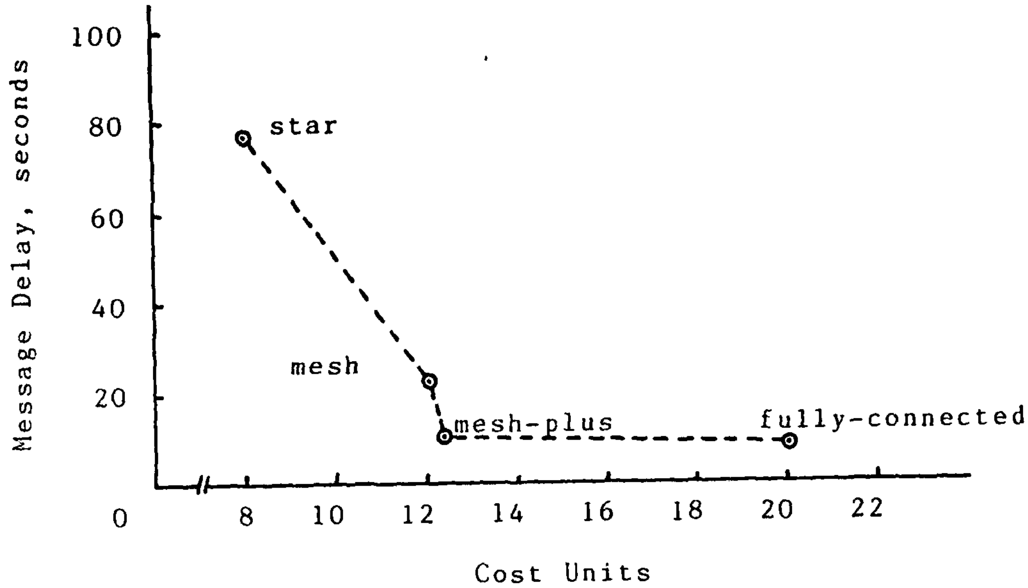


Figure 23: Message delay compared with network cost for a throughput requirement of 12 Kbits/second.

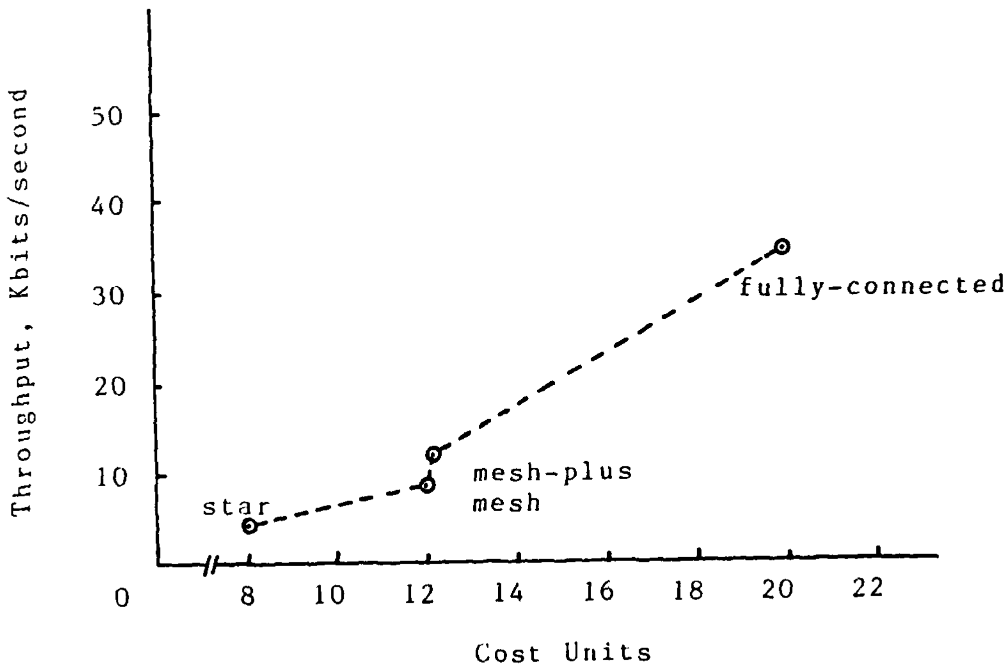


Figure 24: Throughput compared with network cost for a constant message delay of 5.2 seconds.

Four-Level Precedence

The mesh-plus network is used to study a 4-level precedence scheme. Each message is marked with a precedence level which indicates its priority for processing at each queue in the network. Within each precedence level the order of processing is FIFO. The precedence scheme simulated is non-prempting; that is, once a message starts transmission from a node, the arrival of a higher precedence message does not interrupt transmission. Message attribute 4 is marked with an integer from 1, highest, to 4, lowest, to indicate the precedence level. The percentage of messages marked for each level may be selected.

Using a message precedence distribution of 1-10%, 2-10%, 3-30% and 4-50%, message delay performance for the mesh-plus network is shown in figure 25. The highest precedence messages experience the least delay through the network. The lowest precedence messages take longer to pass through the network since they must wait in each queue while all higher precedence traffic is transmitted first.

At low traffic intensities there are fewer messages in the network and the difference in delay between the precedence levels is negligible. As traffic intensity increases, the lowest precedence traffic shows the first sign of increasing delay. Above approximately 200 messages/minute no level 4 messages are processed.

These messages remain in the node queues while higher precedence messages are processed first.

Response Traffic

The effect on network performance due to response traffic is demonstrated using the mesh-plus network. The response probability factors chosen to represent 4 hypothetical situations are shown in table 4. The simulation results for these conditions are shown in figures 26 and 27. Message throughput is plotted against message delay, and message delay is plotted against traffic input.

TABLE 4

MESSAGE RESPONSE TRAFFIC MATRIX

Precedence Level	Probability of a Response			
	Run 1	Run 2	Run 3	Run 4
1	1.0	1.0	1.0	1.0
2	0.5	0.5	0.75	0.9
3	0.1	0.3	0.5	0.6
4	0.0	0.1	0.2	0.5

In each run the original traffic input characteristics remain constant. Only the response traffic assumptions are varied. Throughput performance decreases as response

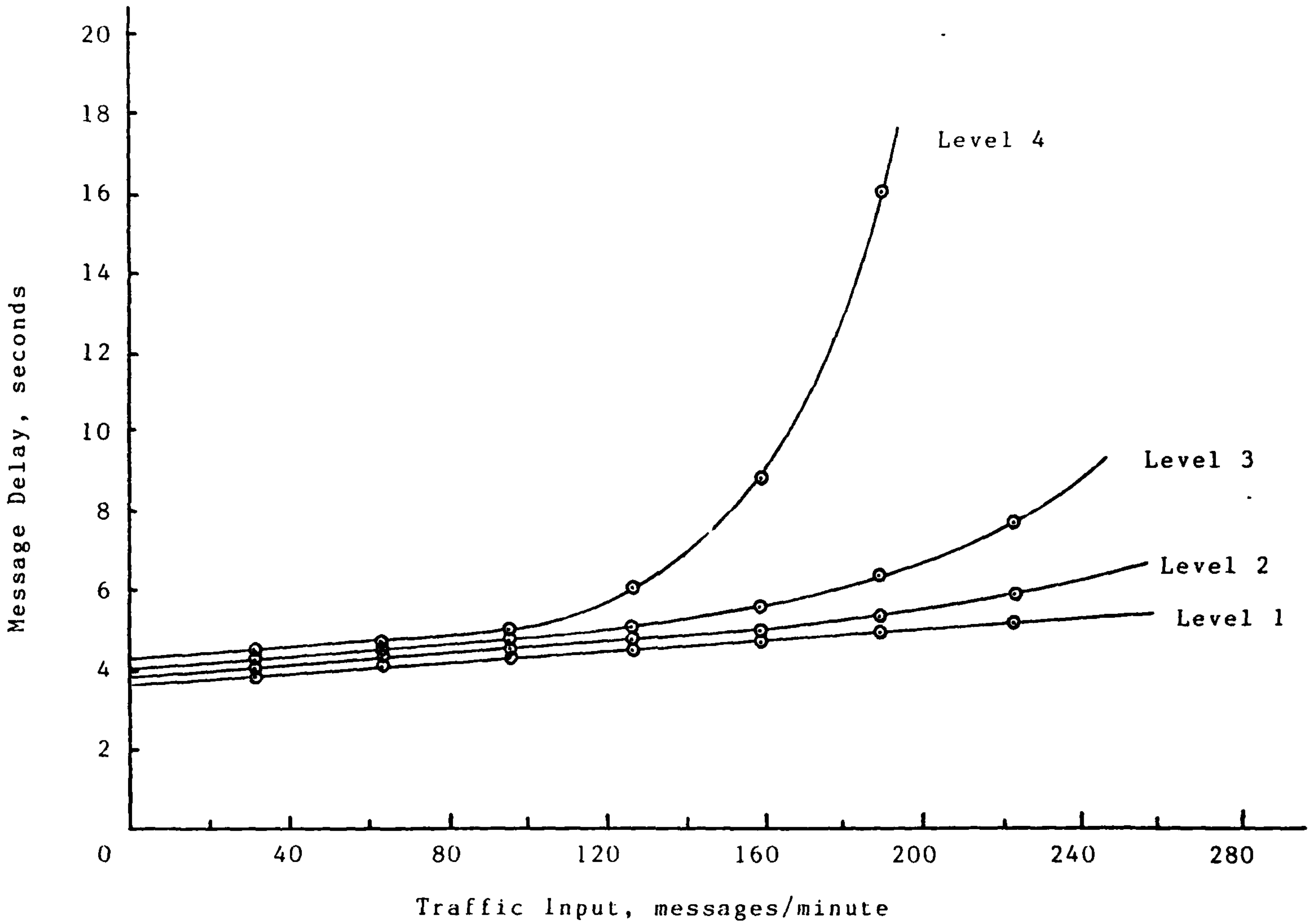


Figure 25: Message delay for precedence levels 1, 2, 3, 4.

traffic increases. Message delay increases as the amount of response traffic increases; however, the change in message delay is only significant at high traffic

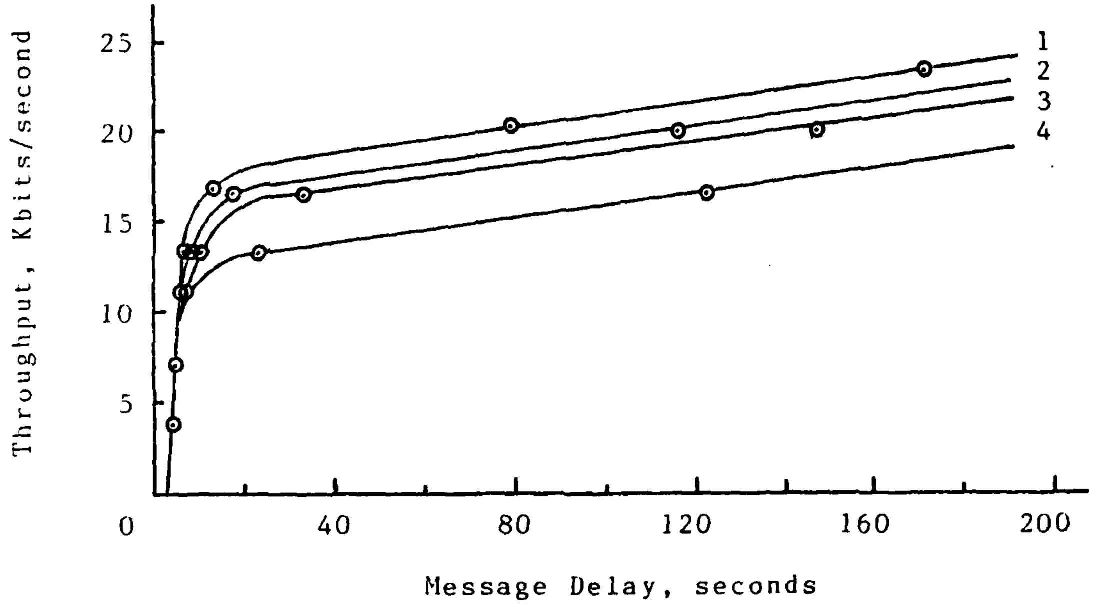


Figure 26: Message throughput for response traffic runs 1, 2, 3, 4 listed in table 4.

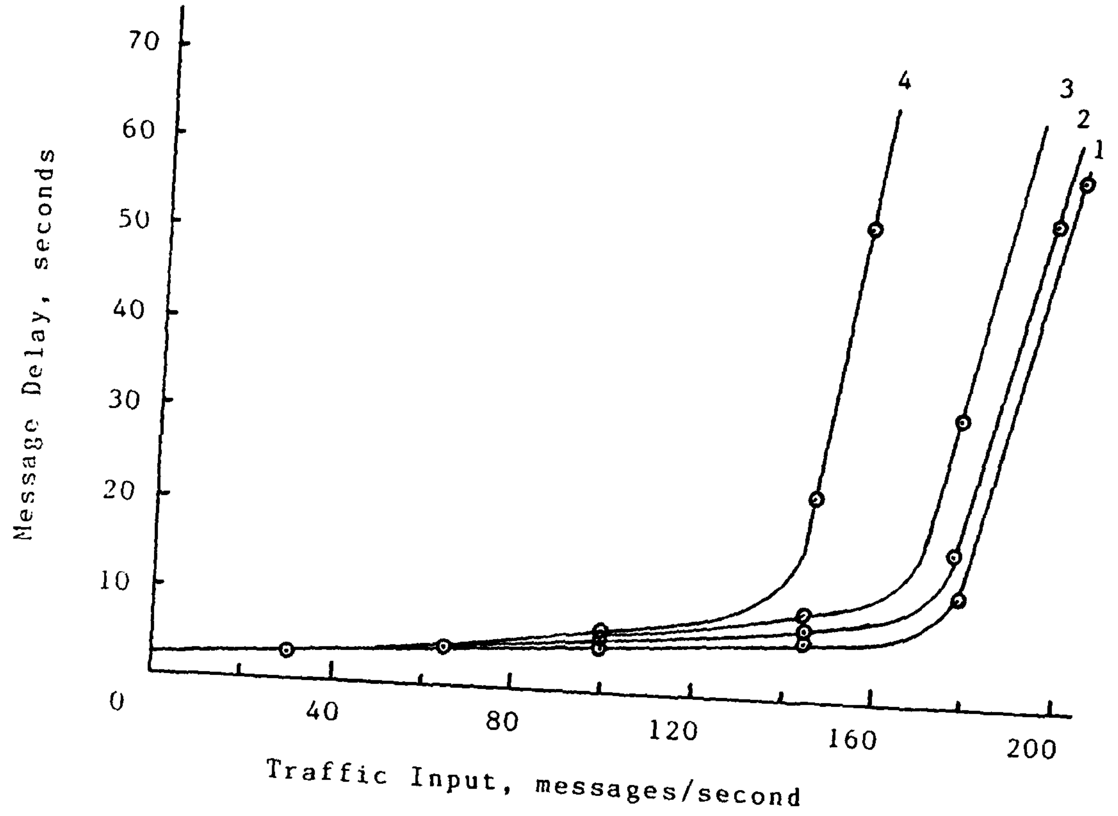


Figure 27: Message delay for the response traffic runs 1, 2, 3, 4 listed in table 4.

intensities. At low traffic intensities the network has sufficient unused capacity to handle the response traffic without causing a significant overall message delay.

ACK/NAK Protocol

The simulations described previously operate with the assumption that all transmissions are error-free. In a real network noise will introduce errors into the messages. Some errors may be corrected using coding schemes implemented in both hardware and software. The time required to accomplish encoding and decoding for error control is included in the simulation in the node processing overhead term. Excessive errors will require the message to be retransmitted.

The mesh-plus network simulation is used to simulate link error rates from 0 to 50 percent. The message performance results are shown in figure 28. As the error rate increases, message delay increases due to the number of retransmissions required. At low traffic intensities a 50 percent error rate results in increasing average message delay by 2-1/2 times.

Message throughput decreases at higher error rates. As the network begins to saturate with retransmitted messages, only the higher precedence messages are transmitted. The lower precedence messages remain in the node queues. For example, with a 50 percent error rate and

a traffic input of 95 messages/minute, precedence level 1 message delay is 18.6 seconds while precedence level 4 message delay under the same conditions is 35 minutes. The average queue length was 153 messages, and the maximum queue length is 701 messages. Clearly, under these conditions only precedence level 1 messages are experiencing an acceptable rate of throughput.

Finite Queue Capacity

The queue capacities in the previous simulations are essentially infinite since queue capacities are set to a large number. The SLAM summary report includes information on the average and maximum queue lengths. Using the queue length and message length, an estimate of the node memory capacity required for each link is made. Assuming a queue length of 20 messages each of 6400 bits, 128 Kbits of message storage is required per link. At node 1 in the mesh network 8 links requires 128 Kbytes of message storage in ASCII code.

To investigate the effects of a finite queue capacity, the maximum queue capacity in the simulation is varied for a series of runs while all other variables areheld constant. When queue lengths reach the maximum level, all arriving messages are rejected. The statistics collected for each link on all rejected messages include

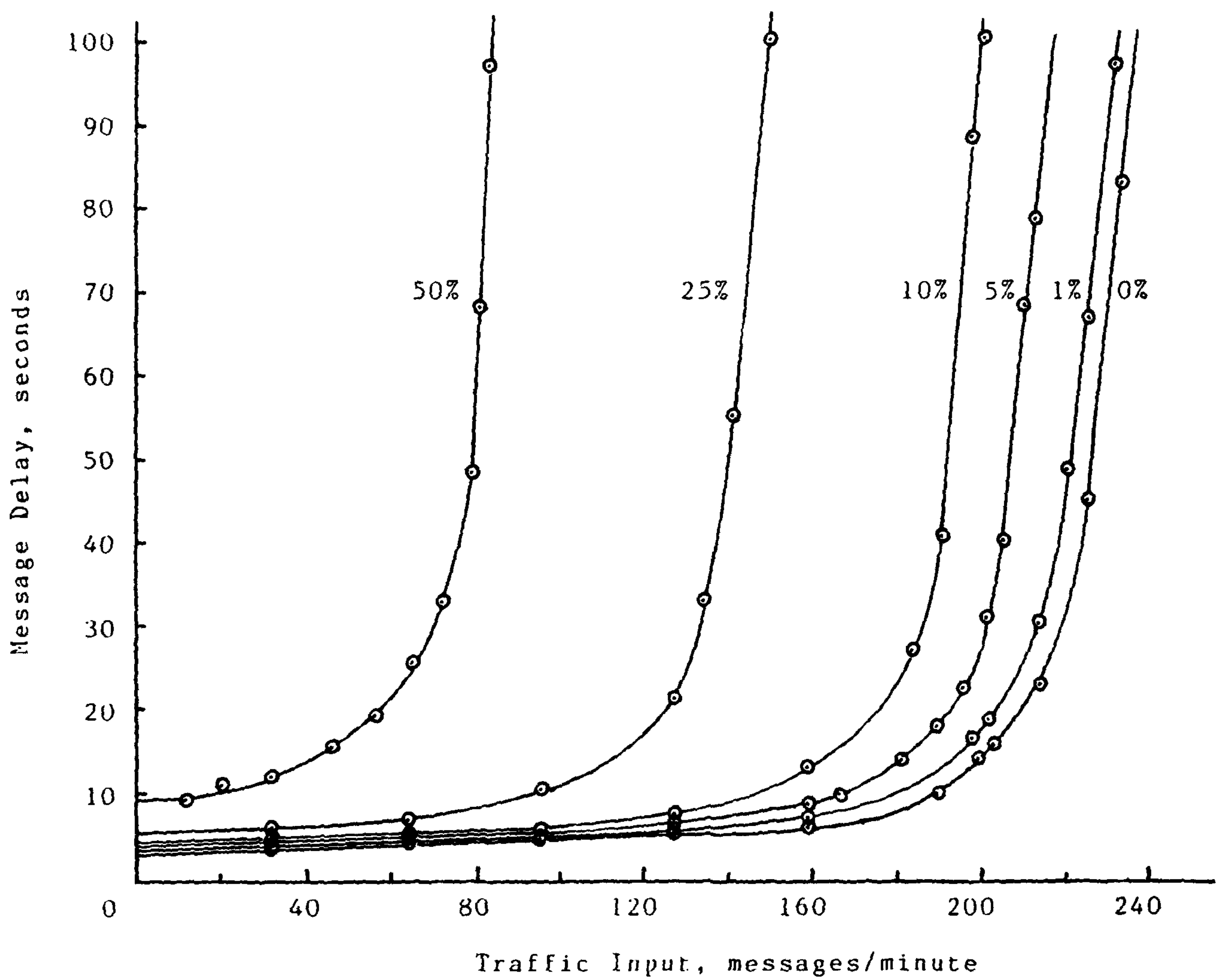


Figure 28: Message delay for link error rates.

the total number of rejections and the average time between message rejections.

The queue activity averaged over all 12 links of the mesh-plus network is shown in figure 29. For a traffic input rate of 189 messages/minute the average queue length is 7 messages. The number of rejected messages per 10,000 transmitted is plotted against queue capacity. For some acceptable level of message rejects, say 5 percent, the minimum queue capacity at this traffic input rate is 16 messages or 12.8 Kbytes of message storage per link.

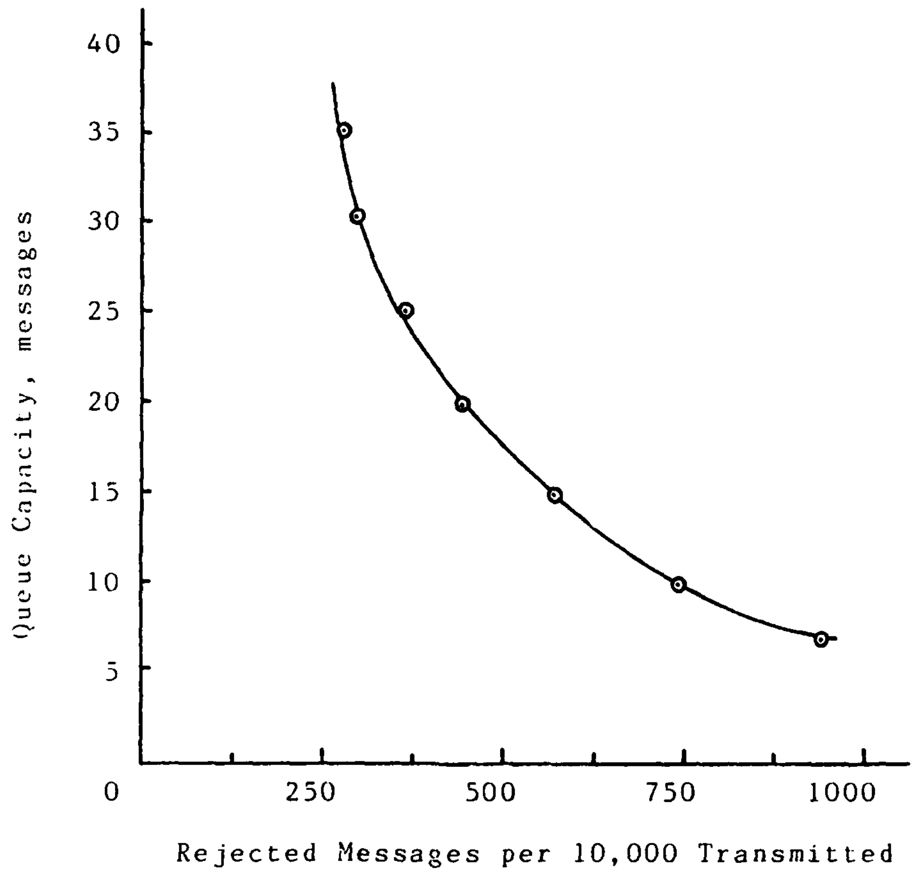


Figure 29: Rejected messages compared with queue capacity for a traffic intensity of 189 messages/second.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

A generalized queueing model simulation of store-and-forward computer communication networks is developed and implemented. The simulation is used to provide realistic and quantitative estimates of network performance by predicting message delay and throughput. This simulation is an effective tool for making comparisons of alternative network designs. The accuracy of the simulation is demonstrated by comparison with published analytic models. The simulation is written using Simulation Language for Alternative Modeling (SLAM). A generalized simulation is achieved by making maximum use of the global variable feature in SLAM.

Discussion of Findings

The simulation provides a clear indication of how message delay performance depends on the input traffic intensity and the network characteristics. The sharp threshold behavior of message delay (and throughput) is estimated for specific network configurations. The star, mesh, mesh-plus and fully-connected networks all show a

sharp threshold for message delay as input traffic increased. When comparing the message delay performance of these networks, there is little difference in the delay when input traffic intensity is low. As traffic increases, each network saturates at a different traffic intensity depending on the topology and link capacity. The simulation gives a performance curve for each network and predicts when network saturation will occur. The performance curves are used in a cost/performance trade-off analysis to optimize a network design.

The 4-level precedence scheme demonstrates that higher precedence traffic users are assured of low message delay even when network traffic intensities increase. At low traffic intensities all users experience approximately the same message delay since there is sufficient network capacity to handle all the traffic. As input traffic increases, the lower precedence users wait in queues while higher precedence traffic is transmitted first. A difference in message delay times of greater than 5 to 1 is observed for the networks simulated. The simulation demonstrates that a network may be shared by users with differing precedence levels and still guarantee the highest precedence users acceptable preformance.

Accurate prediction of network performance depends on accurate simulation of the input traffic. The message generation module allows complete control of all input

traffic characteristics. The response traffic feature provides additional control over the input traffic. Simulating only original traffic requirements without considering that some messages may require the recipient to send a message in response can lead to network designs which will fail under high traffic loads. The simulation demonstrates this effect. At high traffic loads the response traffic decreased throughput by approximately 25 percent.

The effect of data link errors on performance is demonstrated using the ACK/NAK data link protocol feature. As link error rate increased, message delay also increased. The percentage increase in message delay is found to be greater than the error rate percentage. This occurs because there are two components to message delay on error prone links. The message is delayed by being retransmitted and further delayed by waiting for the ACK/NAK message to be transmitted. Consequently, a link error rate of 10 percent causes a reduction in throughput of 19 percent. A 25 percent link error rate reduces throughput by 50 percent. The simulation allows a network designer to identify the magnitude of the effects due to link transmission errors.

The effect of a finite queue capacity is predicted by counting messages that are rejected from the network for insufficient queue space. The simulation estimates the

number of rejected messages as a function of queue capacity. This allows a network designer to determine the memory requirements for the node switching computers.

Conclusions

The SLAM language is an adequate tool for implementing the simulation model. There is some lack of flexibility in the SLAM network language structure which precludes complete generalization of the simulation model. This is not uncommon for a higher order language. For example, the computer communication network topology must be written into the simulation model using node labels in the SLAM network description. Since node labels are constants, the network topology cannot be altered during a simulation run. Changing the network topology is easily accomplished by modifying the node labels in the program listing between simulation runs.

The size of the simulation model is limited in SLAM by the amount of memory space available in the computer used to run the simulation. There is a trade-off between topology, simulation details and the number of message attributes which can be included in a simulation. Each of these must be adjusted so that the available memory space is not exceeded. This is accomplished using the SLAM echo report and by trial and error. As a result, large

network topologies cannot be simulated with the same degree of detail as smaller topologies.

The finite queue capacities are specified in the SLAM language by constants. Since SLAM does not accommodate global variables as queue capacities, the queue specifications cannot be altered during a simulation run. The queue capacities must be modified directly in the program listing between simulation runs.

These limitations on the simulation are considered minor. The advantages of using a simulation language with highly visible and easily modified program statements outweigh any restrictions in the SLAM code. The SLAM language meets the requirement of writing a generalized computer communication network simulation.

Areas for Future Study

The modular structure of this simulation allows adding additional detail to the model without distrubing the existing simulation. For example, premptive queue discipline or variable flow assignment can be added to the simulation. Other data link protocols, possibly including a time-out feature, can be included. The structure and clarity of the SLAM language allows tailoring the simulation to any specific network requirement.

The computer communication network architecture simulated in this study uses store-and-forward message

switching. The links between the nodes represent dedicated communication links such as wire or microwave radio. An alternative network architecture is to replace all the dedicated links with one shared link connecting all network nodes. The single shared link models a radio network accessable to all the nodes. The node-to-node transfer module in the SLAM simulation can be modified to model this network architecture.

APPENDIX A

Single-Server Queue Simulation in SLAM

An example of a single-server queue is programmed in SLAM to illustrate use of the language. A complete tutorial of the SLAM language is found in references [23,24].

In this example message arrivals to an infinite queue have a Poisson distribution and message lengths are exponentially distributed. There is one transmission link out of the queue. Messages are created, placed into the queue and removed one at a time on a first-in-first-out (FIFO) basis for transmission. The total time spent in the queue plus the transmission time is the system delay. The system delay will be estimated using the simulation.

The SLAM graphic symbols for this example are shown in figure 30. Each SLAM symbol is explained below. The attributes and global variable definitions for this example are in table 5.

The results produced by the simulation model are shown in table 6. The simulation model produces results which agree closely with the analytical model.

TABLE 5

SLAM DEFINITIONS FOR SINGLE-SERVER QUEUE

QUANTITY	DEFINITION	VALUE/UNITS
Attribute 1	Message creation time	seconds
Attribute 2	Message length	bits
Attribute 3	Message transmission time	seconds
Global Variable 1	Link capacity	2000 bits /sec
Global Variable 2	Mean message inter-arrival time	0.2 sec
Global Variable 3	Mean message length	100 bits

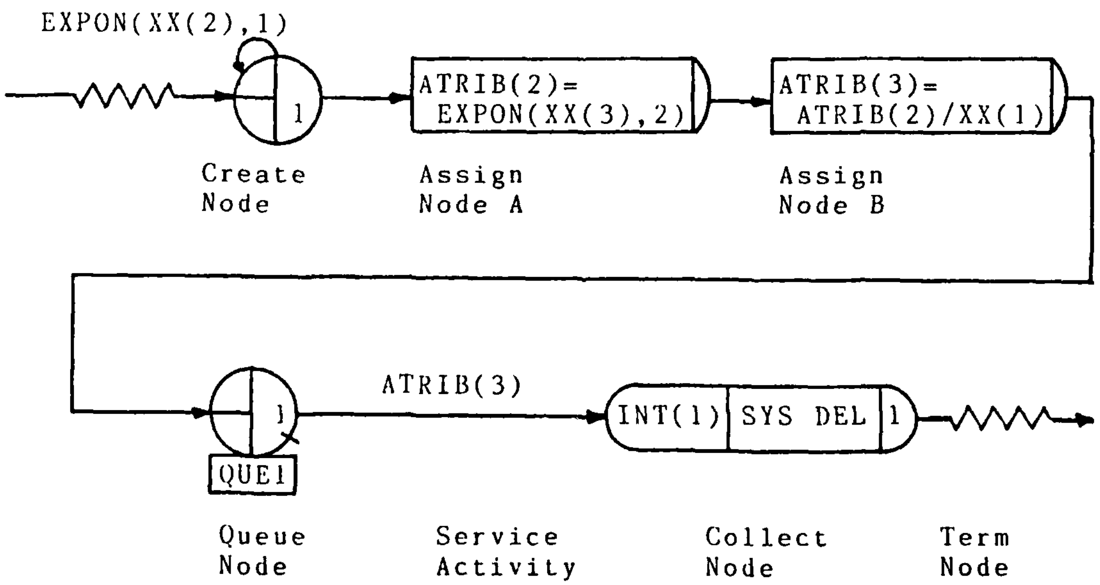


Figure 30: SLAM network for a single-server queue.

CREATE Node

The CREATE node generates messages. The first message is created at time zero. The time between message creations is a random process having an exponential distribution with a mean given by global variable XX(2). Random number stream 1 is used to generate the exponential distribution. For each message created attribute 1 will contain the time the message was created. Only one branch extends from this node.

ASSIGN Node

The ASSIGN node is used to place a value into an attribute of each message which passes through the node. At ASSIGN node A attribute 1 takes a value determined by a random process having an exponential distribution with a mean given by global variable XX(3). Random number stream 2 is used to generate the exponential distribution. Attribute 2 is the message length. At ASSIGN node B attribute 3 takes the value of attribute 2 divided by global variable XX(1). Attribute 3 is the transmission time for the message.

QUEUE Node

The QUEUE node is a location where messages await transmission. Initially, there are no messages in the queue. Queue capacity is infinite. File number 1 is used to store queued messages.

Service ACTIVITY

Service ACTIVITY 1 represents message transmission. It has a duration equal to attribute 3. Only one transmission path is available to the queue.

COLCT Node

A COLCT node is used to collect statistics on entities or variables in a simulation. In this example the interval between attribute 1, message creation time, and the current time is collected as a statistic labeled SYS DEL for system delay. These statistics will appear in the SLAM summary report at the end of the simulation run.

TERM Node

The TERM node is used to remove messages from the simulation. It can also be used to terminate a simulation after a specified number of entities have arrived at the termination node. In this example the termination count is infinite, and the run time for the simulation is determined by a SLAM control statement.

Single-Server Queue Results

Cravis [5] provides a numerical example of a single-server queue based on the Kleinrock model. The message arrival rate λ is 5 messages/second, link capacity C is 2,000 bits/second and the average message length $1/\mu$ is 100 bits. The system delay T is given by $T=1/(\mu C-\lambda)$, and

T=0.06667 seconds. Using these values in the SLAM simulation gives the results shown in table 6. For each of the 10 simulation runs the random number stream was initialized to a different value. The SLAM simulation results agree with the analytical model.

TABLE 6

COMPARISON OF SLAM SIMULATION WITH ANALYTIC MODEL FOR SINGLE-SERVER QUEUE

MODEL	SYSTEM DELAY seconds
Analytic	0.06667
Simulation Run 1	0.06514
2	0.06986
3	0.06426
4	0.05101
5	0.05002
6	0.07521
7	0.07992
8	0.05332
9	0.08055
10	0.07555

APPENDIX B

Simulation Program Listing

The simulation programs were executed on a Control Data Corporation CYBER 845 computer using the operating system NOS 2.2-605/587. The Simulation Language for Alternative Programming was SLAM II version 2.0 available from Pritsker and Associates, Inc., P.O. Box 2413, West Lafayette, Indiana 47906.

Table 7 lists the user specified global variables included in the full simulation model. The full simulation model program listing with sample output is included in this appendix.

TABLE 7

LIST OF USER SPECIFIED GLOBAL VARIABLES

VARIABLE	DEFINITION
XX(1)	Link Transmission Rate is bits/second
XX(3)	Mean Message Length in bits
XX(4)	Minimum Message Length in bits
XX(5)	Maximum Message Length in bits
XX(8)	ACK/NAK Message Length in bits/second
XX(9)	Node Processing Overhead in seconds
XX(11)	Gamma12 and Gamma21 Mean Message Interarrival Time in seconds
XX(12)	Gamma13 and Gamma31 Mean Message Interarrival Time in seconds
XX(13)	Gamma14 and Gamma41 Mean Message Interarrival Time in seconds
XX(14)	Gamma15 and Gamma51 Mean Message Interarrival Time in seconds
XX(15)	Gamma23 and Gamma32 Mean Message Interarrival Time in seconds
XX(16)	Gamma24 and Gamma42 Mean Message Interarrival Time in seconds
XX(17)	Gamma25 and Gamma52 Mean Message Interarrival Time in seconds
XX(18)	Gamma34 and Gamma43 Mean Message Interarrival Time in seconds
XX(19)	Gamma35 and Gamma53 Mean Message Interarrival Time in seconds
XX(20)	Gamma45 and Gamma54 Mean Message Interarrival Time in seconds
XX(31)	Node 1 Message Serial Number Counter
XX(32)	Node 2 Message Serial Number Counter
XX(33)	Node 3 Message Serial Number Counter
XX(34)	Node 4 Message Serial Number Counter
XX(35)	Node 5 Message Serial Number Counter

VARIABLE	DEFINITION
XX(38)	Link12 Error Rate in percent/100
XX(39)	Link13 Error Rate in percent/100
XX(40)	Link14 Error Rate in percent/100
XX(41)	Link15 Error Rate in percent/100
XX(42)	Link21 Error Rate in percent/100
XX(43)	Link23 Error Rate in percent/100
XX(44)	Link31 Error Rate in percent/100
XX(45)	Link32 Error Rate in percent/100
XX(46)	Link34 Error Rate in percent/100
XX(47)	Link41 Error Rate in percent/100
XX(48)	Link43 Error Rate in percent/100
XX(49)	Link51 Error Rate in percent/100
XX(51)	Precedence 1 Traffic Rate in percent/100
XX(52)	Precedence 2 Traffic Rate in percent/100
XX(53)	Precedence 3 Traffic Rate in percent/100
XX(54)	Precedence 4 Traffic Rate in percent/100
XX(61)	Response Rate for Precedence 1 Traffic in percent/100
XX(62)	Response Rate for Precedence 2 Traffic in percent/100
XX(63)	Response Rate for Precedence 3 Traffic in percent/100
XX(64)	Response Rate for Precedence 4 Traffic in percent/100
XX(71)	Number of Lines for Link12
XX(72)	Number of Lines for Link13
XX(73)	Number of Lines for Link14
XX(74)	Number of Lines for Link15
XX(75)	Number of Lines for Link21
XX(76)	Number of Lines for Link23
XX(77)	Number of Lines for Link31
XX(78)	Number of Lines for Link32
XX(79)	Number of Lines for Link34
XX(80)	Number of Lines for Link41
XX(81)	Number of Lines for Link43
XX(82)	Number of Lines for Link51

SLAM II VERSION 2.0

PRITSKER AND ASSOCIATES, INC.
P.O. BOX 2413
WEST LAFAYETTE, INDIANA 47906
(317)463-5557

1

```
GEN,BERT GARCIA,FULL MODEL P24B,02/25/85,5,Y,N,Y,N,Y;
LIMITS,12,7,4000;
;
;
; SIMULATES A COMPUTER COMMUNICATIONS NETWORK WITH FOLLOWING PROPERTIES:
;
;       TOPOLOGY:  MESH NETWORK WITH CONNECTIVITY AS SPECIFIED
;                  IN MESSAGE ROUTING TABLE.  LINK CAPACITY IS
;                  SELECTABLE.
;
;       MESSAGE INPUT:  POISSON PROCESS.  INTERARRIVAL TIMES HAVE
;                       EXPONENTIAL RANDOM DISTRIBUTION WITH RATES
;                       SPECIFIED IN TRAFFIC MATRIX.
;
;       MESSAGE LENGTH:  EXPONENTIAL RANDOM DISTRIBUTION WITH SELECTABLE
;                        MEAN, MAXIMUM AND MINIMUM.
;
;       QUEUE DISCIPLINE:  FOUR-LEVEL PRECEDENCE, HIGHEST PRECEDENCE FIRST.
;
;       QUEUE CAPACITY:  FINITE AS SPECIFIED IN AWAIT NODES.
;
;       LINK PROTOCOL:  ACK/NAK WITH ADJUSTABLE LINK ERROR RATE.
;
;
; GLOBAL VARIABLE DEFINITIONS:
;
;           XX(1)  = LINK TRANSMIT RATE IN BITS/SEC
;           XX(3)  = MEAN MESSAGE LENGTH IN BITS
;           XX(4)  = MINIMUM MESSAGE LENGTH IN BITS
;           XX(5)  = MAXIMUM MESSAGE LENGTH IN BITS
;           XX(8)  = ACK/NAK MESSAGE LENGTH IN BITS/SEC
;           XX(9)  = NODE PROCESSING OVERHEAD IN SEC
;
;           XX(11) = GAMMA12 AND GAMMA21 MEAN MESSAGE INTERARRIVAL TIME
;           XX(12) = GAMMA13 AND GAMMA31 MEAN MESSAGE INTERARRIVAL TIME
```

AD-A162 580 ESTIMATING COMPUTER COMMUNICATION NETWORK PERFORMANCE USING NETWORK SIMULATIONS(U) ARMY MILITARY PERSONNEL CENTER ALEXANDRIA VA A B GARCIA APR 85 2/2

UNCLASSIFIED F/G 17/2 NL

1.0 4.5 5.0 5.6 6.3 7.1 8.0 2.8 3.2 3.6 4.0 2.5 2.2 2.0

1.1 1.8

1.25 1.4 1.6

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

```
;          XX(13) = GAMMA14 AND GAMMA41 MEAN MESSAGE INTERARRIVAL TIME
;          XX(14) = GAMMA15 AND GAMMA51 MEAN MESSAGE INTERARRIVAL TIME
;          XX(15) = GAMMA23 AND GAMMA32 MEAN MESSAGE INTERARRIVAL TIME
;          XX(16) = GAMMA24 AND GAMMA42 MEAN MESSAGE INTERARRIVAL TIME
;          XX(17) = GAMMA25 AND GAMMA52 MEAN MESSAGE INTERARRIVAL TIME
;          XX(18) = GAMMA34 AND GAMMA43 MEAN MESSAGE INTERARRIVAL TIME
;          XX(19) = GAMMA35 AND GAMMA53 MEAN MESSAGE INTERARRIVAL TIME
;          XX(20) = GAMMA45 AND GAMMA54 MEAN MESSAGE INTERARRIVAL TIME
;
;          XX(31) = NODE 1 MESSAGE SERIAL NUMBER COUNTER
;          XX(32) = NODE 2 MESSAGE SERIAL NUMBER COUNTER
;          XX(33) = NODE 3 MESSAGE SERIAL NUMBER COUNTER
;          XX(34) = NODE 4 MESSAGE SERIAL NUMBER COUNTER
;          XX(35) = NODE 5 MESSAGE SERIAL NUMBER COUNTER
;
;          XX(38) = LINK12 ERROR RATE IN PERCENT/100
;          XX(39) = LINK13 ERROR RATE IN PERCENT/100
;          XX(40) = LINK14 ERROR RATE IN PERCENT/100
;          XX(41) = LINK15 ERROR RATE IN PERCENT/100
;          XX(42) = LINK21 ERROR RATE IN PERCENT/100
;          XX(43) = LINK23 ERROR RATE IN PERCENT/100
;          XX(44) = LINK31 ERROR RATE IN PERCENT/100
;          XX(45) = LINK32 ERROR RATE IN PERCENT/100
;          XX(46) = LINK34 ERROR RATE IN PERCENT/100
;          XX(47) = LINK41 ERROR RATE IN PERCENT/100
;          XX(48) = LINK43 ERROR RATE IN PERCENT/100
;          XX(49) = LINK51 ERROR RATE IN PERCENT/100
;
;          XX(51) = PERCENTAGE/100 OF PRECEDENCE 1 TRAFFIC
;          XX(52) = PERCENTAGE/100 OF PRECEDENCE 2 TRAFFIC
;          XX(53) = PERCENTAGE/100 OF PRECEDENCE 3 TRAFFIC
;          XX(54) = PERCENTAGE/100 OF PRECEDENCE 4 TRAFFIC
;
;          XX(61) = PRECEDENCE 1 RESPONSE RATE
;          XX(62) = PRECEDENCE 2 RESPONSE RATE
;          XX(63) = PRECEDENCE 3 RESPONSE RATE
```

```
;           XX(64) = PRECEDENCE 4 RESPONSE RATE
;
;           XX(71) = NUMBER OF LINES FOR LINK12
;           XX(72) = NUMBER OF LINES FOR LINK13
;           XX(73) = NUMBER OF LINES FOR LINK14
;           XX(74) = NUMBER OF LINES FOR LINK15
;           XX(75) = NUMBER OF LINES FOR LINK21
;           XX(76) = NUMBER OF LINES FOR LINK23
;           XX(77) = NUMBER OF LINES FOR LINK31
;           XX(78) = NUMBER OF LINES FOR LINK32
;           XX(79) = NUMBER OF LINES FOR LINK34
;           XX(80) = NUMBER OF LINES FOR LINK41
;           XX(81) = NUMBER OF LINES FOR LINK43
;           XX(82) = NUMBER OF LINES FOR LINK51
;
;
; GLOBAL VARIABLE VALUES:
;
INTLC,
            XX(1)=2400,
            XX(3)=6400,
            XX(4)=100,
            XX(5)=25600,
            XX(8)=3300,
            XX(9)=0.001;
;
INTLC,
            XX(11)=38.095238,
            XX(12)=38.095238,
            XX(13)=38.095238,
            XX(14)=38.095238,
            XX(15)=38.095238,
            XX(16)=38.095238,
            XX(17)=38.095238,
            XX(18)=38.095238,
            XX(19)=38.095238,
```

```
            XX(20)=38.095238;
;
INTLC,
            XX(31)=0,
            XX(32)=0,
            XX(33)=0,
            XX(34)=0,
            XX(35)=0;
;
INTLC,
            XX(38)=0.01,
            XX(39)=0.01,
            XX(40)=0.01,
            XX(41)=0.01,
            XX(42)=0.01,
            XX(43)=0.01,
            XX(44)=0.01,
            XX(45)=0.01,
            XX(46)=0.01,
            XX(47)=0.01,
            XX(48)=0.01,
            XX(49)=0.01;
;
INTLC,
            XX(51)=0.1,
            XX(52)=0.1,
            XX(53)=0.3,
            XX(54)=0.5,
            XX(61)=1.0,
            XX(62)=0.5,
            XX(63)=0.3,
            XX(64)=0.0;
;
INTLC,
            XX(71)=1,
            XX(72)=1,
```

```
          XX(73)=1,
          XX(74)=2,
          XX(75)=1,
          XX(76)=1,
          XX(77)=1,
          XX(78)=1,
          XX(79)=1,
          XX(80)=1,
          XX(81)=1,
          XX(82)=2;
;
; MESSAGE ATTRIBUTES:
;
;         ATRIB(1) = MESSAGE CREATION TIME
;         ATRIB(2) = MESSAGE DESTINATION NODE
;         ATRIB(3) = MESSAGE TYPE
;         ATRIB(4) = MESSAGE PRECEDENCE
;         ATRIB(5) = MESSAGE ORIGIN NODE
;         ATRIB(6) = MESSAGE SERIAL NUMBER
;         ATRIB(7) = MESSAGE LENGTH
;
;
; INPUT TRAFFIC MATRIX:
;   VALUES SHOWN ARE FOR NETWORK UTILIZATION FACTOR RHO=0.1.
;   MATRIX IS USUALLY SYMMETRICAL.  ENTRIES ARE 1/GJK.
;
;                                      TO
;          NODE      1          2          3          4          5
;                 ________   ________   ________   ________   ________
;           1        -      38.095238  38.095238  38.095238  38.095238
;    FROM   2    38.095238      -      38.095238  38.095238  38.095238
;           3    38.095238  38.095238      -      38.095238  38.095238
;           4    38.095238  38.095238  38.095238      -      38.095238
;           5    38.095238  38.095238  38.095238  38.095238      -
;
;
```

```
; MESSAGE PRECEDENCE SCHEME:
;
;                    ATRIB(4)     PRECEDENCE      PERCENT
;                    ------------------------------------
;                       1          HIGHEST           10
;                       2             .              10
;                       3             .              30
;                       4          LOWEST            50
;
;
; MESSAGE TYPE DEFINITIONS:
;
;                    ATRIB(3)       TYPE
;                    -----------------------
;                       0          ORIGINAL
;                       1          RESPONSE
;
;
; MESSAGE RESPONSE TRAFFIC MATRIX:
;
;                    PRECEDENCE       PERCENT RESPONSE
;                    ---------------------------------
;                       1                  100
;                       2                   50
;                       3                   30
;                       4                    0
;
```

```
;
; MESSAGE ROUTING TABLE:
;
;                                       TO
;                   NODE    1     2     3     4     5
;                   ------------------------------------
;                    1      -     2     3     4     5
;        FROM        2      1     -     3     3     1
;                    3      1     2     -     4     1
;                    4      1     3     3     -     1
;                    5      1     1     1     1     -
;
; NODE QUEUES ARE IMPLEMENTED USING RESOURCE FILES REPRESENTING
;  COMMUNICATION LINKS.  AVAILABLE LINKS FOR THIS NETWORK ARE:
;
;                   NODE 1  NODE 2  NODE 3  NODE 4  NODE 5
;                   ------  ------  ------  ------  ------
;                   LINK12  LINK21  LINK31  LINK41  LINK51
;                   LINK13  LINK23  LINK32  LINK43
;                   LINK14          LINK34
;                   LINK15
;
; QUEUE CAPACITY:  25 MESSAGES.
;
;----------------------------------------------------------------
;
;                ***** NETWORK TOPOLOGY DESCRIPTION *****
;
NETWORK;
;
; LINK RESOURCES DEFINE NETWORK CONNECTIVITY.
     RESOURCE/LINK12(0),1/LINK13(0),2/LINK14(0),3/LINK15(0),4;
     RESOURCE/LINK21(0),5/LINK23(0),6;
     RESOURCE/LINK31(0),7/LINK32(0),8/LINK34(0),9;
     RESOURCE/LINK41(0),10/LINK43(0),11;
     RESOURCE/LINK51(0),12;
```

```
;
; ALTER NUMBER OF LINES FOR EACH LINK.
     CREATE,,,,1,1;                    CREATE ONE DUMMY MESSAGE
     ALTER,LINK12/XX(71),1;             TO ALTER EACH LINK WITH
     ALTER,LINK13/XX(72),1;             REQUIRED NUMBER OF LINES.
     ALTER,LINK14/XX(73),1;
     ALTER,LINK15/XX(74),1;
     ALTER,LINK21/XX(75),1;
     ALTER,LINK23/XX(76),1;
     ALTER,LINK31/XX(77),1;
     ALTER,LINK32/XX(78),1;
     ALTER,LINK34/XX(79),1;
     ALTER,LINK41/XX(80),1;
     ALTER,LINK43/XX(81),1;
     ALTER,LINK51/XX(82),1;
     TERM;                             DISCARD DUMMY MESSSAGE
;
;                        END OF NETWORK TOPOLOGY DESCRIPTION
;
;    ******************************************************************
;    *                                                                *
;    *                   MESSAGE GENERATION                           *
;    *                                                                *
;
; EACH ORIGIN NODE HAS A SEPARATE TRAFFIC GENERATOR STATEMENT FOR EACH
;  DESTINATION NODE.
;
; ** NODE 1 **
; CREATE MESSAGES AND STORE CREATION TIME IN ATRIB(1).  RANDOM TIME
;  BETWEEN MESSAGE CREATIONS HAS MEAN VALUE GIVEN BY GLOBAL VARIABLE.
;  MESSAGE PRECEDENCE LEVEL IS DETERMINED BY PROBABILITY BRANCHING AND
;  INDICATED IN ATRIBUTE 4.  CREATED MESSAGE IS PLACED IN THE
;  PROPER TRANSMIT QUEUE ACCORDING TO THE ROUTING TABLE.
;
```

```
; TRAFFIC TO NODE 2:
C1    CREATE,EXPON(XX(11),1),,1;                        CREATE MESSAGE
      ASSIGN,ATRIB(2)=2,ATRIB(3)=0,ATRIB(5)=1,1;        ASSIGN DESTN, TYPE, ORIGIN
      ASSIGN,ATRIB(7)=EXPON(XX(3),1),1;                 ASSIGN MESSAGE LENGTH
      ASSIGN,XX(31)=XX(31)+1,1;                         INCREMENT SER NUM COUNTER
      ASSIGN,ATRIB(6)=XX(31),1;                         ASSIGN SERIAL NUMBER
      GOON,1;
      ACT,,ATRIB(7).LE.XX(4),C1M;                       CHECK FOR MINIMUM LENGTH
      ACT,,ATRIB(7).GE.XX(5),C1X;                       CHECK FOR MAXIMUM LENGTH
      ACT,,,C1P;
C1M   ASSIGN,ATRIB(7)=XX(4);                            ASSIGN MINIMUM LENGTH
      ACT,,,C1P;
C1X   ASSIGN,ATRIB(7)=XX(5);                            ASSIGN MAXIMUM LENGTH
      ACT,,,C1P;
C1P   GOON,1;
      ACT,,XX(51),C1A;                                  DISTRIB MSGS BY PRECEDENCE
      ACT,,XX(52),C1B;
      ACT,,XX(53),C1C;
      ACT,,XX(54),C1D;
C1A   ASSIGN,ATRIB(4)=1;                                ASSIGN PR 1
      ACT,,,Q12;                                        PUT MSG IN OUTGOING QUEUE
C1B   ASSIGN,ATRIB(4)=2;                                ASSIGN PR 2
      ACT,,,Q12;                                        PUT MSG IN OUTGOING QUEUE
C1C   ASSIGN,ATRIB(4)=3;                                ASSIGN PR 3
      ACT,,,Q12;                                        PUT MSG IN OUTGOING QUEUE
C1D   ASSIGN,ATRIB(4)=4;                                ASSIGN PR 4
      ACT,,,Q12;                                        PUT MSG IN OUTGOING QUEUE
;
; TRAFFIC TO NODE 3:
C2    CREATE,EXPON(XX(12),2),,1;                        CREATE MESSAGE
      ASSIGN,ATRIB(2)=3,ATRIB(3)=0,ATRIB(5)=1,1;        ASSIGN DESTN, TYPE, ORIGIN
      ASSIGN,ATRIB(7)=EXPON(XX(3),2),1;                 ASSIGN MESSAGE LENGTH
      ASSIGN,XX(31)=XX(31)+1,1;                         INCREMENT SER NUM COUNTER
      ASSIGN,ATRIB(6)=XX(31),1;                         ASSIGN SERIAL NUMBER
      GOON,1;
      ACT,,ATRIB(7).LE.XX(4),C2M;                       CHECK FOR MINIMUM LENGTH
```

```
      ACT,,ATRIB(7).GE.XX(5),C2X;                    CHECK FOR MAXIMUM LENGTH
      ACT,,,C2P;
C2M   ASSIGN,ATRIB(7)=XX(4);                         ASSIGN MINIMUM LENGTH
      ACT,,,C2P;
C2X   ASSIGN,ATRIB(7)=XX(5);                         ASSIGN MAXIMUM LENGTH
      ACT,,,C2P;
C2P   GOON,1;
      ACT,,XX(51),C2A;                               DISTRIB MSGS BY PRECEDENCE
      ACT,,XX(52),C2B;
      ACT,,XX(53),C2C;
      ACT,,XX(54),C2D;
C2A   ASSIGN,ATRIB(4)=1;                             ASSIGN PR 1
      ACT,,,Q13;                                     PUT MSG IN OUTGOING QUEUE
C2B   ASSIGN,ATRIB(4)=2;                             ASSIGN PR 2
      ACT,,,Q13;                                     PUT MSG IN OUTGOING QUEUE
C2C   ASSIGN,ATRIB(4)=3;                             ASSIGN PR 3
      ACT,,,Q13;                                     PUT MSG IN OUTGOING QUEUE
C2D   ASSIGN,ATRIB(4)=4;                             ASSIGN PR 4
      ACT,,,Q13;                                     PUT MSG IN OUTGOING QUEUE
;
; TRAFFIC TO NODE 4:
C3    CREATE,EXPON(XX(12),3),,1;                     CREATE MESSAGE
      ASSIGN,ATRIB(2)=4,ATRIB(3)=0,ATRIB(5)=1,1;     ASSIGN DESTN, TYPE, ORIGIN
      ASSIGN,ATRIB(7)=EXPON(XX(3),3),1;              ASSIGN MESSAGE LENGTH
      ASSIGN,XX(31)=XX(31)+1,1;                      INCREMENT SER NUM COUNTER
      ASSIGN,ATRIB(6)=XX(31),1;                      ASSIGN SER NUM
      GOON,1;
      ACT,,ATRIB(7).LE.XX(4),C3M;                    CHECK FOR MINIMUM LENGTH
      ACT,,ATRIB(7).GE.XX(5),C3X;                    CHECK FOR MAXIMUM LENGTH
      ACT,,,C3P;
C3M   ASSIGN,ATRIB(7)=XX(4);                         ASSIGN MINIMUM LENGTH
      ACT,,,C3P;
C3X   ASSIGN,ATRIB(7)=XX(5);                         ASSIGN MAXIMUM LENGTH
      ACT,,,C3P;
C3P   GOON,1;
      ACT,,XX(51),C3A;                               DISTRIB MSGS BY PRECEDENCE
```

```
        ACT,,XX(52),C3B;
        ACT,,XX(53),C3C;
        ACT,,XX(54),C3D;
C3A     ASSIGN,ATRIB(4)=1;                            ASSIGN PR 1
        ACT,,,Q14;                                    PUT MSG IN OUTGOING QUEUE
C3B     ASSIGN,ATRIB(4)=2;                            ASSIGN PR 2
        ACT,,,Q14;                                    PUT MSG IN OUTGOING QUEUE
C3C     ASSIGN,ATRIB(4)=3;                            ASSIGN PR 3
        ACT,,,Q14;                                    PUT MSG IN OUTGOING QUEUE
C3D     ASSIGN,ATRIB(4)=4;                            ASSIGN PR 4
        ACT,,,Q14;                                    PUT MSG IN OUTGOING QUEUE
;
; TRAFFIC TO NODE 5:
C4      CREATE,EXPON(XX(14),4),,1;                    CREATE MESSAGE
        ASSIGN,ATRIB(2)=5,ATRIB(3)=0,ATRIB(5)=1,1;    ASSIGN DESTN, TYPE, ORIGIN
        ASSIGN,ATRIB(7)=EXPON(XX(3),4),1;             ASSIGN MESSAGE LENGTH
        ASSIGN,XX(31)=XX(31)+1,1;                     INCREMENT SER NUM COUNTER
        ASSIGN,ATRIB(6)=XX(31),1;                     ASSIGN SERIAL NUMBER
        GOON,1;
        ACT,,ATRIB(7).LE.XX(4),C4M;                   CHECK FOR MINIMUM LENGTH
        ACT,,ATRIB(7).GE.XX(5),C4X;                   CHECK FOR MAXIMUM LENGTH
        ACT,,,C4P;
C4M     ASSIGN,ATRIB(7)=XX(4);                        ASSIGN MINIMUM LENGTH
        ACT,,,C4P;
C4X     ASSIGN,ATRIB(7)=XX(5);                        ASSIGN MAXIMUM LENGTH
        ACT,,,C4P;
C4P     GOON,1;
        ACT,,XX(51),C4A;                              DISTRIB MSGS BY PRECEDENCE
        ACT,,XX(52),C4B;
        ACT,,XX(53),C4C;
        ACT,,XX(54),C4D;
C4A     ASSIGN,ATRIB(4)=1;                            ASSIGN PR 1
        ACT,,,Q15;                                    PUT MSG IN OUTGOING QUEUE
C4B     ASSIGN,ATRIB(4)=2;                            ASSIGN PR 2
        ACT,,,Q15;                                    PUT MSG IN OUTGOING QUEUE
C4C     ASSIGN,ATRIB(4)=3;                            ASSIGN PR 3
```

```
      ACT,,,Q15;                                 PUT MSG IN OUTGOING QUEUE
C4D   ASSIGN,ATRIB(4)=4;                         ASSIGN PR 4
      ACT,,,Q15;                                 PUT MSG IN OUTGOING QUEUE
;
;                                      END OF NODE 1 GENERATOR
; ** NODE 2 **
;
; TRAFFIC TO NODE 1:
C5    CREATE,EXPON(XX(11),5),,1;
      ASSIGN,ATRIB(2)=1,ATRIB(3)=0,ATRIB(5)=2,1;
      ASSIGN,ATRIB(7)=EXPON(XX(3),5),1;
      ASSIGN,XX(32)=XX(32)+1,1;
      ASSIGN,ATRIB(6)=XX(32),1;
      GOON,1;
      ACT,,ATRIB(7).LE.XX(4),C5M;
      ACT,,ATRIB(7).GE.XX(5),C5X;
      ACT,,,C5P;
C5M   ASSIGN,ATRIB(7)=XX(4);
      ACT,,,C5P;
C5X   ASSIGN,ATRIB(7)=XX(5);
      ACT,,,C5P;
C5P   GOON,1;
      ACT,,XX(51),C5A;
      ACT,,XX(52),C5B;
      ACT,,XX(53),C5C;
      ACT,,XX(54),C5D;
C5A   ASSIGN,ATRIB(4)=1;
      ACT,,,Q21;
C5B   ASSIGN,ATRIB(4)=2;
      ACT,,,Q21;
C5C   ASSIGN,ATRIB(4)=3;
      ACT,,,Q21;
C5D   ASSIGN,ATRIB(4)=4;
      ACT,,,Q21;
;
; TRAFFIC TO NODE 3:
```

```
C6   CREATE,EXPON(XX(15),6),,1;
     ASSIGN,ATRIB(2)=3,ATRIB(3)=0,ATRIB(5)=2,1;
     ASSIGN,ATRIB(7)=EXPON(XX(3),6),1;
     ASSIGN,XX(32)=XX(32)+1,1;
     ASSIGN,ATRIB(6)=XX(32),1;
     GOON,1;
     ACT,,ATRIB(7).LE.XX(4),C6M;
     ACT,,ATRIB(7).GE.XX(5),C6X;
     ACT,,,C6P;
C6M  ASSIGN,ATRIB(7)=XX(4);
     ACT,,,C6P;
C6X  ASSIGN,ATRIB(7)=XX(5);
     ACT,,,C6P;
C6P  GOON,1;
     ACT,,XX(51),C6A;
     ACT,,XX(52),C6B;
     ACT,,XX(53),C6C;
     ACT,,XX(54),C6D;
C6A  ASSIGN,ATRIB(4)=1;
     ACT,,,Q23;
C6B  ASSIGN,ATRIB(4)=2;
     ACT,,,Q23;
C6C  ASSIGN,ATRIB(4)=3;
     ACT,,,Q23;
C6D  ASSIGN,ATRIB(4)=4;
     ACT,,,Q23;
;
; TRAFFIC TO NODE 4:
C7   CREATE,EXPON(XX(16),7),,1;
     ASSIGN,ATRIB(2)=4,ATRIB(3)=0,ATRIB(5)=2,1;
     ASSIGN,ATRIB(7)=EXPON(XX(3),7),1;
     ASSIGN,XX(32)=XX(32)+1,1;
     ASSIGN,ATRIB(6)=XX(32),1;
     GOON,1;
     ACT,,ATRIB(7).LE.XX(4),C7M;
     ACT,,ATRIB(7).GE.XX(5),C7X;
```

```
      ACT,,,C7P;
C7M   ASSIGN,ATRIB(7)=XX(4);
      ACT,,,C7P;
C7X   ASSIGN,ATRIB(7)=XX(5);
      ACT,,,C7P;
C7P   GOON,1;
      ACT,,XX(51),C7A;
      ACT,,XX(52),C7B;
      ACT,,XX(53),C7C;
      ACT,,XX(54),C7D;
C7A   ASSIGN,ATRIB(4)=1;
      ACT,,,Q23;
C7B   ASSIGN,ATRIB(4)=2;
      ACT,,,Q23;
C7C   ASSIGN,ATRIB(4)=3;
      ACT,,,Q23;
C7D   ASSIGN,ATRIB(4)=4;
      ACT,,,Q23;
;
; TRAFFIC TO NODE 5:
C8    CREATE,EXPON(XX(17),8),,1;
      ASSIGN,ATRIB(2)=5,ATRIB(3)=0,ATRIB(5)=2,1;
      ASSIGN,ATRIB(7)=EXPON(XX(3),8),1;
      ASSIGN,XX(32)=XX(32)+1,1;
      ASSIGN,ATRIB(6)=XX(32),1;
      GOON,1;
      ACT,,ATRIB(7).LE.XX(4),C8M;
      ACT,,ATRIB(7).GE.XX(5),C8X;
      ACT,,,C8P;
C8M   ASSIGN,ATRIB(7)=XX(4);
      ACT,,,C8P;
C8X   ASSIGN,ATRIB(7)=XX(5);
      ACT,,,C8P;
C8P   GOON,1;
      ACT,,XX(51),C8A;
      ACT,,XX(52),C8B;
```

```
      ACT,,XX(53),C8C;
      ACT,,XX(54),C8D;
C8A   ASSIGN,ATRIB(4)=1;
      ACT,,,Q21;
C8B   ASSIGN,ATRIB(4)=2;
      ACT,,,Q21;
C8C   ASSIGN,ATRIB(4)=3;
      ACT,,,Q21;
C8D   ASSIGN,ATRIB(4)=4;
      ACT,,,Q21;                              END OF NODE 2 GENERATOR
;
; ** NODE 3 **
;
; TRAFFIC TO NODE 1:
C9    CREATE,EXPON(XX(12),1),,1;
      ASSIGN,ATRIB(2)=1,ATRIB(3)=0,ATRIB(5)=3,1;
      ASSIGN,ATRIB(7)=EXPON(XX(3),1),1;
      ASSIGN,XX(33)=XX(33)+1,1;
      ASSIGN,ATRIB(6)=XX(33),1;
      GOON,1;
      ACT,,ATRIB(7).LE.XX(4),C9M;
      ACT,,ATRIB(7).GE.XX(5),C9X;
      ACT,,,C9P;
C9M   ASSIGN,ATRIB(7)=XX(4);
      ACT,,,C9P;
C9X   ASSIGN,ATRIB(7)=XX(5);
      ACT,,,C9P;
C9P   GOON,1;
      ACT,,XX(51),C9A;
      ACT,,XX(52),C9B;
      ACT,,XX(53),C9C;
      ACT,,XX(54),C9D;
C9A   ASSIGN,ATRIB(4)=1;
      ACT,,,Q31;
C9B   ASSIGN,ATRIB(4)=2;
      ACT,,,Q31;
```

```
C9C  ASSIGN,ATRIB(4)=3;
     ACT,,,Q31;
C9D  ASSIGN,ATRIB(4)=4;
     ACT,,,Q31;
;
; TRAFFIC TO NODE 2:
C10  CREATE,EXPON(XX(15),2),,1;
     ASSIGN,ATRIB(2)=2,ATRIB(3)=0,ATRIB(5)=3,1;
     ASSIGN,ATRIB(7)=EXPON(XX(3),2),1;
     ASSIGN,XX(33)=XX(33)+1,1;
     ASSIGN,ATRIB(6)=XX(33),1;
     GOON,1;
     ACT,,ATRIB(7).LE.XX(4),C10M;
     ACT,,ATRIB(7).GE.XX(5),C10X;
     ACT,,,C10P;
C10M ASSIGN,ATRIB(7)=XX(4);
     ACT,,,C10P;
C10X ASSIGN,ATRIB(7)=XX(5);
     ACT,,,C10P;
C10P GOON,1;
     ACT,,XX(51),C10A;
     ACT,,XX(52),C10B;
     ACT,,XX(53),C10C;
     ACT,,XX(54),C10D;
C10A ASSIGN,ATRIB(4)=1;
     ACT,,,Q32;
C10B ASSIGN,ATRIB(4)=2;
     ACT,,,Q32;
C10C ASSIGN,ATRIB(4)=3;
     ACT,,,Q32;
C10D ASSIGN,ATRIB(4)=4;
     ACT,,,Q32;
;
; TRAFFIC TO NODE 4:
C11  CREATE,EXPON(XX(18),3),,1;
     ASSIGN,ATRIB(2)=4,ATRIB(3)=0,ATRIB(5)=3,1;
```

```
      ASSIGN,ATRIB(7)=EXPON(XX(3),3),1;
      ASSIGN,XX(33)=XX(33)+1,1;
      ASSIGN,ATRIB(6)=XX(33),1;
      GOON,1;
      ACT,,ATRIB(7).LE.XX(4),C11M;
      ACT,,ATRIB(7).GE.XX(5),C11X;
      ACT,,,C11P;
C11M  ASSIGN,ATRIB(7)=XX(4);
      ACT,,,C11P;
C11X  ASSIGN,ATRIB(7)=XX(5);
      ACT,,,C11P;
C11P  GOON,1;
      ACT,,XX(51),C11A;
      ACT,,XX(52),C11B;
      ACT,,XX(53),C11C;
      ACT,,XX(54),C11D;
C11A  ASSIGN,ATRIB(4)=1;
      ACT,,,Q34;
C11B  ASSIGN,ATRIB(4)=2;
      ACT,,,Q34;
C11C  ASSIGN,ATRIB(4)=3;
      ACT,,,Q34;
C11D  ASSIGN,ATRIB(4)=4;
      ACT,,,Q34;
;
; TRAFFIC TO NODE 5:
C12   CREATE,EXPON(XX(19),4),,1;
      ASSIGN,ATRIB(2)=5,ATRIB(3)=0,ATRIB(5)=3,1;
      ASSIGN,ATRIB(7)=EXPON(XX(3),4),1;
      ASSIGN,XX(33)=XX(33)+1,1;
      ASSIGN,ATRIB(6)=XX(33),1;
      GOON,1;
      ACT,,ATRIB(7).LE.XX(4),C12M;
      ACT,,ATRIB(7).GE.XX(5),C12X;
      ACT,,,C12P;
C12M  ASSIGN,ATRIB(7)=XX(4);
```

```
      ACT,,,C12P;
C12X  ASSIGN,ATRIB(7)=XX(5);
      ACT,,,C12P;
C12P  COON,1;
      ACT,,XX(51),C12A;
      ACT,,XX(52),C12B;
      ACT,,XX(53),C12C;
      ACT,,XX(54),C12D;
C12A  ASSIGN,ATRIB(4)=1;
      ACT,,,Q31;
C12B  ASSIGN,ATRIB(4)=2;
      ACT,,,Q31;
C12C  ASSIGN,ATRIB(4)=3;
      ACT,,,Q31;
C12D  ASSIGN,ATRIB(4)=4;
      ACT,,,Q31;                          END OF NODE 3 GENERATOR
;
; ** NODE 4 **
;
; TRAFFIC TO NODE 1:
C13   CREATE,EXPON(XX(13),5),,1;
      ASSIGN,ATRIB(2)=1,ATRIB(3)=0,ATRIB(5)=4,1;
      ASSIGN,ATRIB(7)=EXPON(XX(3),5),1;
      ASSIGN,XX(34)=XX(34)+1,1;
      ASSIGN,ATRIB(6)=XX(34),1;
      COON,1;
      ACT,,ATRIB(7).LE.XX(4),C13M;
      ACT,,ATRIB(7).GE.XX(5),C13X;
      ACT,,,C13P;
C13M  ASSIGN,ATRIB(7)=XX(4);
      ACT,,,C13P;
C13X  ASSIGN,ATRIB(7)=XX(5);
      ACT,,,C13P;
C13P  COON,1;
      ACT,,XX(51),C13A;
      ACT,,XX(52),C13B;
```

```
      ACT,,XX(53),C13C;
      ACT,,XX(54),C13D;
C13A  ASSIGN,ATRIB(4)=1;
      ACT,,,Q41;
C13B  ASSIGN,ATRIB(4)=2;
      ACT,,,Q41;
C13C  ASSIGN,ATRIB(4)=3;
      ACT,,,Q41;
C13D  ASSIGN,ATRIB(4)=4;
      ACT,,,Q41;
;
; TRAFFIC TO NODE 2:
C14   CREATE,EXPON(XX(16),6),,1;
      ASSIGN,ATRIB(2)=2,ATRIB(3)=0,ATRIB(5)=4,1;
      ASSIGN,ATRIB(7)=EXPON(XX(3),6),1;
      ASSIGN,XX(34)=XX(34)+1,1;
      ASSIGN,ATRIB(6)=XX(34),1;
      GOON,1;
      ACT,,ATRIB(7).LE.XX(4),C14M;
      ACT,,ATRIB(7).GE.XX(5),C14X;
      ACT,,,C14P;
C14M  ASSIGN,ATRIB(7)=XX(4);
      ACT,,,C14P;
C14X  ASSIGN,ATRIB(7)=XX(5);
      ACT,,,C14P;
C14P  GOON,1;
      ACT,,XX(51),C14A;
      ACT,,XX(52),C14B;
      ACT,,XX(53),C14C;
      ACT,,XX(54),C14D;
C14A  ASSIGN,ATRIB(4)=1;
      ACT,,,Q43;
C14B  ASSIGN,ATRIB(4)=2;
      ACT,,,Q43;
C14C  ASSIGN,ATRIB(4)=3;
      ACT,,,Q43;
```

```
C14D  ASSIGN,ATRIB(4)=4;
      ACT,,,Q43;
;
; TRAFFIC TO NODE 3:
C15   CREATE,EXPON(XX(18),7),,1;
      ASSIGN,ATRIB(2)=3,ATRIB(3)=0,ATRIB(5)=4,1;
      ASSIGN,ATRIB(7)=EXPON(XX(3),7),1;
      ASSIGN,XX(34)=XX(34)+1,1;
      ASSIGN,ATRIB(6)=XX(34),1;
      GOON,1;
      ACT,,ATRIB(7).LE.XX(4),C15M;
      ACT,,ATRIB(7).GE.XX(5),C15X;
      ACT,,,C15P;
C15M  ASSIGN,ATRIB(7)=XX(4);
      ACT,,,C15P;
C15X  ASSIGN,ATRIB(7)=XX(5);
      ACT,,,C15P;
C15P  GOON,1;
      ACT,,XX(51),C15A;
      ACT,,XX(52),C15B;
      ACT,,XX(53),C15C;
      ACT,,XX(54),C15D;
C15A  ASSIGN,ATRIB(4)=1;
      ACT,,,Q43;
C15B  ASSIGN,ATRIB(4)=2;
      ACT,,,Q43;
C15C  ASSIGN,ATRIB(4)=3;
      ACT,,,Q43;
C15D  ASSIGN,ATRIB(4)=4;
      ACT,,,Q43;
;
; TRAFFIC TO NODE 5:
C16   CREATE,EXPON(XX(20),8),,1;
      ASSIGN,ATRIB(2)=5,ATRIB(3)=0,ATRIB(5)=4,1;
      ASSIGN,ATRIB(7)=EXPON(XX(3),8),1;
      ASSIGN,XX(34)=XX(34)+1,1;
```

```
     ASSIGN,ATRIB(6)=XX(34),1;
     GOON,1;
     ACT,,ATRIB(7).LE.XX(4),C16M;
     ACT,,ATRIB(7).GE.XX(5),C16X;
     ACT,,,C16P;
C16M ASSIGN,ATRIB(7)=XX(4);
     ACT,,,C16P;
C16X ASSIGN,ATRIB(7)=XX(5);
     ACT,,,C16P;
C16P GOON,1;
     ACT,,XX(51),C16A;
     ACT,,XX(52),C16B;
     ACT,,XX(53),C16C;
     ACT,,XX(54),C16D;
C16A ASSIGN,ATRIB(4)=1;
     ACT,,,Q41;
C16B ASSIGN,ATRIB(4)=2;
     ACT,,,Q41;
C16C ASSIGN,ATRIB(4)=3;
     ACT,,,Q41;
C16D ASSIGN,ATRIB(4)=4;
     ACT,,,Q41;                        END OF NODE 4 GENERATOR
;
; ** NODE 5 **
;
; TRAFFIC TO NODE 1:
C17  CREATE,EXPON(XX(14),1),,1;
     ASSIGN,ATRIB(2)=1,ATRIB(3)=0,ATRIB(5)=5,1;
     ASSIGN,ATRIB(7)=EXPON(XX(3),1),1;
     ASSIGN,XX(35)=XX(35)+1,1;
     ASSIGN,ATRIB(6)=XX(35),1;
     GOON,1;
     ACT,,ATRIB(7).LE.XX(4),C17M;
     ACT,,ATRIB(7).GE.XX(5),C17X;
     ACT,,,C17P;
C17M ASSIGN,ATRIB(7)=XX(4);
```

```
       ACT,,,C17P;
C17X   ASSIGN,ATRIB(7)=XX(5);
       ACT,,,C17P;
C17P   GOON,1;
       ACT,,XX(51),C17A;
       ACT,,XX(52),C17B;
       ACT,,XX(53),C17C;
       ACT,,XX(54),C17D;
C17A   ASSIGN,ATRIB(4)=1;
       ACT,,,Q51;
C17B   ASSIGN,ATRIB(4)=2;
       ACT,,,Q51;
C17C   ASSIGN,ATRIB(4)=3;
       ACT,,,Q51;
C17D   ASSIGN,ATRIB(4)=4;
       ACT,,,Q51;
;
; TRAFFIC TO NODE 2:
C18    CREATE,EXPON(XX(17),2),,1;
       ASSIGN,ATRIB(2)=2,ATRIB(3)=0,ATRIB(5)=5,1;
       ASSIGN,ATRIB(7)=EXPON(XX(3),2),1;
       ASSIGN,XX(35)=XX(35)+1,1;
       ASSIGN,ATRIB(6)=XX(35),1;
       GOON,1;
       ACT,,ATRIB(7).LE.XX(4),C18M;
       ACT,,ATRIB(7).GE.XX(5),C18X;
       ACT,,,C18P;
C18M   ASSIGN,ATRIB(7)=XX(4);
       ACT,,,C18P;
C18X   ASSIGN,ATRIB(7)=XX(5);
       ACT,,,C18P;
C18P   GOON,1;
       ACT,,XX(51),C18A;
       ACT,,XX(52),C18B;
       ACT,,XX(53),C18C;
       ACT,,XX(54),C18D;
```

```
C18A  ASSIGN,ATRIB(4)=1;
      ACT,,,Q51;
C18B  ASSIGN,ATRIB(4)=2;
      ACT,,,Q15;
C18C  ASSIGN,ATRIB(4)=3;
      ACT,,,Q15;
C18D  ASSIGN,ATRIB(4)=4;
      ACT,,,Q51;
;
; TRAFFIC TO NODE 3:
C19   CREATE,EXPON(XX(19),3),,1;
      ASSIGN,ATRIB(2)=3,ATRIB(3)=0,ATRIB(5)=5,1;
      ASSIGN,ATRIB(7)=EXPON(XX(3),3),1;
      ASSIGN,XX(35)=XX(35)+1,1;
      ASSIGN,ATRIB(6)=XX(35),1;
      GOON,1;
      ACT,,ATRIB(7).LE.XX(4),C19M;
      ACT,,ATRIB(7).GE.XX(5),C19X;
      ACT,,,C19P;
C19M  ASSIGN,ATRIB(7)=XX(4);
      ACT,,,C19P;
C19X  ASSIGN,ATRIB(7)=XX(5);
      ACT,,,C19P;
C19P  GOON,1;
      ACT,,XX(51),C19A;
      ACT,,XX(52),C19B;
      ACT,,XX(53),C19C;
      ACT,,XX(54),C19D;
C19A  ASSIGN,ATRIB(4)=1;
      ACT,,,Q51;
C19B  ASSIGN,ATRIB(4)=2;
      ACT,,,Q51;
C19C  ASSIGN,ATRIB(4)=3;
      ACT,,,Q51;
C19D  ASSIGN,ATRIB(4)=4;
      ACT,,,Q51;
```

```
;
; TRAFFIC TO NODE 4:
C20  CREATE,EXPON(XX(20),4),,1;
     ASSIGN,ATRIB(2)=4,ATRIB(3)=0,ATRIB(5)=5,1;
     ASSIGN,ATRIB(7)=EXPON(XX(3),4),1;
     ASSIGN,XX(35)=XX(35)+1,1;
     ASSIGN,ATRIB(6)=XX(35),1;
     GOON,1;
     ACT,,ATRIB(7).LE.XX(4),C20M;
     ACT,,ATRIB(7).GE.XX(5),C20X;
     ACT,,,C20P;
C20M ASSIGN,ATRIB(7)=XX(4);
     ACT,,,C20P;
C20X ASSIGN,ATRIB(7)=XX(5);
     ACT,,,C20P;
C20P GOON,1;
     ACT,,XX(51),C20A;
     ACT,,XX(52),C20B;
     ACT,,XX(53),C20C;
     ACT,,XX(54),C20D;
C20A ASSIGN,ATRIB(4)=1;
     ACT,,,Q51;
C20B ASSIGN,ATRIB(4)=2;
     ACT,,,Q51;
C20C ASSIGN,ATRIB(4)=3;
     ACT,,,Q51;
C20D ASSIGN,ATRIB(4)=4;
     ACT,,,Q51;                          END OF NODE 5 GENERATOR
;
;                          END OF MESSAGE GENERATION
```

```
;
;     ***********************************************************************
;     *                                                                     *
;     *                          NODE PROCESSING                            *
;     *                                                                     *
;
; ** NODE 1 **
;
; INCOMING MESSAGES ARE CHECKED FOR DESTINATION.  IF THE DESTINATION
;  IS NODE 1 OR IF THERE ARE NO ROUTING INSTRUCTIONS, THE MESSAGE
;  IS PASSED TO STATISTICS COLLECTION.  IF THE DESTINATION IS OTHER
;  THAN NODE 1, MESSAGE IS PUT INTO QUEUE FOR TRANSMISSION.
;  THERE IS A SEPARATE QUEUE FOR EACH OUTGOING LINK.
;
N11   GOON,1;
      ACT,XX(9);                        NODE PROCESSING OVERHEAD
      GOON,1;
      ACT,,ATRIB(2).EQ.2,Q12;           DETERMINE DESTINATION NODE
      ACT,,ATRIB(2).EQ.3,Q13;
      ACT,,ATRIB(2).EQ.4,Q14;
      ACT,,ATRIB(2).EQ.5,Q15;
      ACT,,,TUT;
;
;                                       END OF NODE 1
; ** NODE 2 **
;
N21   GOON,1;
      ACT,XX(9);
      GOON,1;
      ACT,,ATRIB(2).EQ.1,Q21;
      ACT,,ATRIB(2).EQ.3,Q23;
      ACT,,ATRIB(2).EQ.4,Q23;
      ACT,,ATRIB(2).EQ.5,Q21;
      ACT,,,TUT;
;
;                                       END OF NODE 2
```

```
; ** NODE 3 **
;
N31   GOON,1;
      ACT,XX(9);
      GOON,1;
      ACT,,ATRIB(2).EQ.1,Q31;
      ACT,,ATRIB(2).EQ.2,Q32;
      ACT,,ATRIB(2).EQ.4,Q34;
      ACT,,ATRIB(2).EQ.5,Q31;
      ACT,,,TUT;
;
;                              END OF NODE 3
; ** NODE 4 **
;
N41   GOON,1;
      ACT,XX(9);
      GOON,1;
      ACT,,ATRIB(2).EQ.1,Q41;
      ACT,,ATRIB(2).EQ.2,Q43;
      ACT,,ATRIB(2).EQ.3,Q43;
      ACT,,ATRIB(2).EQ.5,Q41;
      ACT,,,TUT;
;
;                              END OF NODE 4
; ** NODE 5 **
;
N51   GOON,1;
      ACT,XX(9);
      GOON,1;
      ACT,,ATRIB(2).EQ.1,Q51;
      ACT,,ATRIB(2).EQ.2,Q51;
      ACT,,ATRIB(2).EQ.3,Q51;
      ACT,,ATRIB(2).EQ.4,Q51;
      ACT,,,TUT;
;
;                              END OF NODE 5
```

```
;
;                              END OF NODE PROCESSING
;
;     ****************************************************************
;     *                                                              *
;     *                        NODE-TO-NODE TRANSFER                 *
;     *                                                              *
;
; MESSAGES READY FOR TRANSMISSION ARE KEPT IN AN OUTGOING QUEUE AND
;  REMOVED ONE AT A TIME FOR TRANSMISSION USING A FIFO DISCIPLINE.
;  MESSAGE TRANSMISSION TIME DEPENDS ON MESSAGE LENGTH AND
;  CHANNEL RATE.
;
; ** NODE 1 **
;
Q12   GOON,1;
      ACT,,,CH12;
CH12  AWAIT(1/25),LINK12,BALK(OV12),1;     CAPTURE THE LINK
      ACT,ATRIB(7)/XX(1),1-XX(38),F12;     TRANSMIT WITH NO ERRORS
      ACT,ATRIB(7)/XX(1),XX(38),F12A;      TRANSMIT WITH ERRORS
F12A  GOON,1;
      ACT,XX(8)/XX(1),,F12B;               TRANSMIT NAK
F12B  GOON,1;
      ACT,ATRIB(7)/XX(1),1-XX(38),F12;     RETRANSMIT WITH NO ERRORS
      ACT,ATRIB(7)/XX(1),XX(38),F12A;      RETRANSMIT WITH ERRORS
F12   GOON,1;
      ACT,XX(8)/XX(1),,F12F;               TRANSMIT ACK
F12F  FREE,LINK12,1;                       RELEASE THE LINK
      ACT,,,N21;                           NODE LABEL NX1 DEFINES TOPOLOGY
;
Q13   GOON,1;
      ACT,,,CH13;
CH13  AWAIT(2/25),LINK13,BALK(OV13),1;     CAPTURE THE LINK
      ACT,ATRIB(7)/XX(1),1-XX(39),F13;     TRANSMIT WITH NO ERRORS
      ACT,ATRIB(7)/XX(1),XX(39),F13A;      TRANSMIT WITH ERRORS
F13A  GOON,1;
```

```
       ACT,XX(8)/XX(1),,F13B;                TRANSMIT NAK
F13B   GOON,1;
       ACT,ATRIB(7)/XX(1),1-XX(39),F13;      RETRANSMIT WITH NO ERRORS
       ACT,ATRIB(7)/XX(1),XX(39),F13A;       RETRANSMIT WITH ERRORS
F13    GOON,1;
       ACT,XX(8)/XX(1),,F13F;                TRANSMIT ACK
F13F   FREE,LINK13,1;                        RELEASE THE LINK
       ACT,,,N31;                            NODE LABEL NX1 DEFINES TOPOLOGY
;
Q14    GOON,1;
       ACT,,,CH14;
CH14   AWAIT(3/25),LINK14,BALK(OV14),1;      CAPTURE THE LINK
       ACT,ATRIB(7)/XX(1),1-XX(40),F14;      TRANSMIT WITH NO ERRORS
       ACT,ATRIB(7)/XX(1),XX(40),F14A;       TRANSMIT WITH ERRORS
F14A   GOON,1;
       ACT,XX(8)/XX(1),,F14B;                TRANSMIT NAK
F14B   GOON,1;
       ACT,ATRIB(7)/XX(1),1-XX(40),F14;      RETRANSMIT WITH NO ERRORS
       ACT,ATRIB(7)/XX(1),XX(40),F14A;       RETRANSMIT WITH ERRORS
F14    GOON,1;
       ACT,XX(8)/XX(1),,F14F;                TRANSMIT ACK
F14F   FREE,LINK14,1;                        RELEASE THE LINK
       ACT,,,N41;                            NODE LABEL NX1 DEFINES TOPOLOGY
;
Q15    GOON,1;
       ACT,,,CH15;
CH15   AWAIT(4/25),LINK15,BALK(OV15),1;      CAPTURE THE LINK
       ACT,ATRIB(7)/XX(1),1-XX(41),F15;      TRANSMIT WITH NO ERRORS
       ACT,ATRIB(7)/XX(1),XX(41),F15A;       TRANSMIT WITH ERRORS
F15A   GOON,1;
       ACT,XX(8)/XX(1),,F15B;                TRANSMIT NAK
F15B   GOON,1;
       ACT,ATRIB(7)/XX(1),1-XX(41),F15;      RETRANSMIT WITH NO ERRORS
       ACT,ATRIB(7)/XX(1),XX(41),F15A;       RETRANSMIT WITH ERRORS
F15    GOON,1;
       ACT,XX(8)/XX(1),,F15F;                TRANSMIT ACK
```

```
F15F  FREE,LINK15,1;                          RELEASE THE LINK
      ACT,,,N51;                              NODE LABEL NX1 DEFINES TOPOLOGY
;
;                                             END OF NODE 1
;
; ** NODE 2 **
;
Q21   GOON,1;
      ACT,,,CH21;
CH21  AWAIT(5/25),LINK21,BALK(OV21),1;
      ACT,ATRIB(7)/XX(1),1-XX(42),F21;
      ACT,ATRIB(7)/XX(1),XX(42),F21A;
F21A  GOON,1;
      ACT,XX(8)/XX(1),,F21B;
F21B  GOON,1;
      ACT,ATRIB(7)/XX(1),1-XX(42),F21;
      ACT,ATRIB(7)/XX(1),XX(42),F21A;
F21   GOON,1;
      ACT,XX(8)/XX(1),,F21F;
F21F  FREE,LINK21,1;
      ACT,,,N11;
;
Q23   GOON,1;
      ACT,,,CH23;
CH23  AWAIT(6/25),LINK23,BALK(OV23),1;
      ACT,ATRIB(7)/XX(1),1-XX(43),F23;
      ACT,ATRIB(7)/XX(1),XX(43),F23A;
F23A  GOON,1;
      ACT,XX(8)/XX(1),,F23B;
F23B  GOON,1;
      ACT,ATRIB(7)/XX(1),1-XX(43),F23;
      ACT,ATRIB(7)/XX(1),XX(43),F23A;
F23   GOON,1;
      ACT,XX(8)/XX(1),,F23F;
F23F  FREE,LINK23,1;
      ACT,,,N31;
```

```
;
;                                END OF NODE 2
;
; ** NODE 3 **
;
Q31   GOON,1;
      ACT,,,CH31;
CH31  AWAIT(7/25),LINK31,BALK(OV31),1;
      ACT,ATRIB(7)/XX(1),1-XX(44),F31;
      ACT,ATRIB(7)/XX(1),XX(44),F31A;
F31A  GOON,1;
      ACT,XX(8)/XX(1),,F31B;
F31B  GOON,1;
      ACT,ATRIB(7)/XX(1),1-XX(44),F31;
      ACT,ATRIB(7)/XX(1),XX(44),F31A;
F31   GOON,1;
      ACT,XX(8)/XX(1),,F31F;
F31F  FREE,LINK31,1;
      ACT,,,N11;
;
Q32   GOON,1;
      ACT,,,CH32;
CH32  AWAIT(8/25),LINK32,BALK(OV32),1;
      ACT,ATRIB(7)/XX(1),1-XX(45),F32;
      ACT,ATRIB(7)/XX(1),XX(45),F32A;
F32A  GOON,1;
      ACT,XX(8)/XX(1),,F32B;
F32B  GOON,1;
      ACT,ATRIB(7)/XX(1),1-XX(45),F32;
      ACT,ATRIB(7)/XX(1),XX(45),F32A;
F32   GOON,1;
      ACT,XX(8)/XX(1),,F32F;
F32F  FREE,LINK32,1;
      ACT,,,N21;
;
Q34   GOON,1;
```

```
        ACT,,,CH34;
CH34    AWAIT(9/25),LINK34,BALK(OV34),1;
        ACT,ATRIB(7)/XX(1),1-XX(46),F34;
        ACT,ATRIB(7)/XX(1),XX(46),F34A;
F34A    GOON,1;
        ACT,XX(8)/XX(1),,F34B;
F34B    GOON,1;
        ACT,ATRIB(7)/XX(1),1-XX(46),F34;
        ACT,ATRIB(7)/XX(1),XX(46),F34A;
F34     GOON,1;
        ACT,XX(8)/XX(1),,F34F;
F34F    FREE,LINK34,1;
        ACT,,,N41;
;
;                                        END OF NODE 3
;
; ** NODE 4 **
;
Q41     GOON,1;
        ACT,,,CH41;
CH41    AWAIT(10/25),LINK41,BALK(OV41),1;
        ACT,ATRIB(7)/XX(1),1-XX(47),F41;
        ACT,ATRIB(7)/XX(1),XX(47),F41A;
F41A    GOON,1;
        ACT,XX(8)/XX(1),,F41B;
F41B    GOON,1;
        ACT,ATRIB(7)/XX(1),1-XX(47),F41;
        ACT,ATRIB(7)/XX(1),XX(47),F41A;
F41     GOON,1;
        ACT,XX(8)/XX(1),,F41F;
F41F    FREE,LINK41,1;
        ACT,,,N11;
;
Q43     GOON,1;
        ACT,,,CH43;
CH43    AWAIT(11/25),LINK43,BALK(OV43),1;
```

```
     ACT,ATRIB(7)/XX(1),1-XX(48),F43;
     ACT,ATRIB(7)/XX(1),XX(48),F43A;
F43A GOON,1;
     ACT,XX(8)/XX(1),,F43B;
F43B GOON,1;
     ACT,ATRIB(7)/XX(1),1-XX(48),F43;
     ACT,ATRIB(7)/XX(1),XX(48),F43A;
F43  GOON,1;
     ACT,XX(8)/XX(1),,F43F;
F43F FREE,LINK43,1;
     ACT,,,N31;
;
;                                  END OF NODE 4
;
; ** NODE 5 **
;
Q51  GOON,1;
     ACT,,,CH51;
CH51 AWAIT(12/25),LINK51,BALK(OV51),1;
     ACT,ATRIB(7)/XX(1),1-XX(49),F51;
     ACT,ATRIB(7)/XX(1),XX(49),F51A;
F51A GOON,1;
     ACT,XX(8)/XX(1),,F51B;
F51B GOON,1;
     ACT,ATRIB(7)/XX(1),1-XX(49),F51;
     ACT,ATRIB(7)/XX(1),XX(49),F51A;
F51  GOON,1;
     ACT,XX(8)/XX(1),,F51F;
F51F FREE,LINK51,1;
     ACT,,,N11;
;
;                                  END OF NODE 5
;
;                    END OF NODE-TO-NODE TRANSFER
```

```
;
;     ********************************************************************
;     *                                                                  *
;     *                    STATISITICS COLLECTION                        *
;     *                                                                  *
;
; STATISTICS ARE COLLECTED ON THE TOTAL TIME THAT A MESSAGE
;  IS IN THE NETWORK.  STATISTICS ARE COLLECTED AND REPORTED
;  BY PRECEDENCE LEVEL.
;
; SLAM SUMMARY REPORT LABELS:
;
;         TIS TOT  = TOTAL TIME IN SYSTEM FOR ALL MESSAGES
;         TIS PR 1 = TOTAL TIME IN SYSTEM FOR PRECEDENCE 1 MESSAGES ONLY
;         TIS PR 2 = TOTAL TIME IN SYSTEM FOR PRECEDENCE 2 MESSAGES ONLY
;         TIS PR 3 = TOTAL TIME IN SYSTEM FOR PRECEDENCE 3 MESSAGES ONLY
;         TIS PR 4 = TOTAL TIME IN SYSTEM FOR PRECEDENCE 4 MESSAGES ONLY
;         OVR 12   = MEAN TIME BETWEEN OVERFLOW ON LINK12
;         OVR 13   = MEAN TIME BETWEEN OVERFLOW ON LINK13
;         OVR 14   = MEAN TIME BETWEEN OVERFLOW ON LINK14
;         OVR 15   = MEAN TIME BETWEEN OVERFLOW ON LINK15
;         OVR 21   = MEAN TIME BETWEEN OVERFLOW ON LINK21
;         OVR 23   = MEAN TIME BETWEEN OVERFLOW ON LINK23
;         OVR 31   = MEAN TIME BETWEEN OVERFLOW ON LINK31
;         OVR 32   = MEAN TIME BETWEEN OVERFLOW ON LINK32
;         OVR 34   = MEAN TIME BETWEEN OVERFLOW ON LINK34
;         OVR 41   = MEAN TIME BETWEEN OVERFLOW ON LINK41
;         OVR 43   = MEAN TIME BETWEEN OVERFLOW ON LINK43
;         OVR 51   = MEAN TIME BETWEEN OVERFLOW ON LINK51
;
TOT   COLCT,INT(1),TIS TOT,,1;
      ACT,,ATRIB(4).EQ.1,TOT1;
      ACT,,ATRIB(4).EQ.2,TOT2;
      ACT,,ATRIB(4).EQ.3,TOT3;
      ACT,,ATRIB(4).EQ.4,TOT4;
TOT1  COLCT,INT(1),TIS PR 1,,1;
```

```
      ACT,,,TOT5;
TOT2  COLCT,INT(1),TIS PR 2,,1;
      ACT,,,TOT5;
TOT3  COLCT,INT(1),TIS PR 3,,1;
      ACT,,,TOT5;
TOT4  COLCT,INT(1),TIS PR 4,,1;
TOT5  GOON,2;
      ACT,,,EXT;                PERFORM EXTERNAL EFFECTS
      ACT;
      TERM,10000;               ALL MESSAGES ARE COUNTED
;
;
; STATISTICS ARE COLLECTED ON MESSAGES WHICH ARE REJECTED AT A NODE
;  FOR INSUFFICIENT QUEUE CAPACITY.
;
OV12  COLCT,BETWEEN,OVR 12,,1;
      TERM;                           DISCARD OVERFLOW
OV13  COLCT,BETWEEN,OVR 13,,1;
      TERM;
OV14  COLCT,BETWEEN,OVR 14,,1;
      TERM;
OV15  COLCT,BETWEEN,OVR 15,,1;
      TERM;
OV21  COLCT,BETWEEN,OVR 21,,1;
      TERM;
OV23  COLCT,BETWEEN,OVR 23,,1;
      TERM;
OV31  COLCT,BETWEEN,OVR 31,,1;
      TERM;
OV32  COLCT,BETWEEN,OVR 32,,1;
      TERM;
OV34  COLCT,BETWEEN,OVR 34,,1;
      TERM;
OV41  COLCT,BETWEEN,OVR 41,,1;
      TERM;
OV43  COLCT,BETWEEN,OVR 43,,1;
```

```
      TERM;
OV51  COLCT,BETWEEN,OVR 51,,1;
      TERM;
;
;                        END OF STATISTICS COLLECTION
;
;     ******************************************************************
;     *                                                                *
;     *                      EXTERNAL EFFECTS                          *
;     *                                                                *
;
EXT   COUN,1;
      ACT,,,EXR;                 PERFORM RESPONSE TRAFFIC
;
; *** RESPONSE TRAFFIC ***
;
; RESPONSE TRAFFIC IS GENERATED BASED ON PRECEDENCE LEVEL
;  OF ORIGINAL MESSAGE.   ARRIVING RESPONSE MESSAGES DO NOT
;  GENERATE ANOTHER RESPONSE AND ARE DISCARDED.
;
EXR   COUN,1;
      ACT,,ATRIB(3).EQ.0,EXR1;          PROCESS ONLY ORIGINAL MESSSAGES
      ACT;
      TERM;
;
; DETERMINE DESTINATION NODE OF ORIGINAL MESSAGE.  SET ATRIB(1)
;  TO CURRENT TIME.  MARK ATRIB(3) AS RESPONSE TRAFFIC.
;
EXR1  ASSIGN,ATRIB(1)=TNOW,ATRIB(3)=1,1;
      ACT,,ATRIB(2).EQ.1,EX1;
      ACT,,ATRIB(2).EQ.2,EX2;
      ACT,,ATRIB(2).EQ.3,EX3;
      ACT,,ATRIB(2).EQ.4,EX4;
      ACT,,ATRIB(2).EQ.5,EX5;
```

```
;
; RESPONSE TRAFFIC IS RETURNED TO EACH NODE FOR TRANSMISSION.
;  ORIGIN OF ORIGINAL MESSAGE IS USED AS DESTINATION.
;  PRECEDENCE OF MESSAGE DETERMINES HOW MUCH RESPONSE
;  TRAFFIC IS GENERATED.
;
; ** NODE 1 **
;
EX1   ASSIGN,ATRIB(2)=ATRIB(5);
      GOON,1;                                   SORT ON PRECEDENCE
      ACT,,ATRIB(4).EQ.1,EX11;
      ACT,,ATRIB(4).EQ.2,EX12;
      ACT,,ATRIB(4).EQ.3,EX13;
      ACT,,ATRIB(4).EQ.4,EX14;
EX11  GOON,1;
      ACT,,XX(61),N11;
      ACT,,1-XX(61);
      TERM;
EX12  GOON,1;
      ACT,,XX(62),N11;
      ACT,,1-XX(62);
      TERM;
EX13  GOON,1;
      ACT,,XX(63),N11;
      ACT,,1-XX(63);
      TERM;
EX14  GOON,1;
      ACT,,XX(64),N11;
      ACT,,1-XX(64);
      TERM;
;                                            END OF NODE 1
;
; ** NODE 2 **
;
EX2   ASSIGN,ATRIB(2)=ATRIB(5);
      GOON,1;
```

```
      ACT,,ATRIB(4).EQ.1,EX21;
      ACT,,ATRIB(4).EQ.2,EX22;
      ACT,,ATRIB(4).EQ.3,EX23;
      ACT,,ATRIB(4).EQ.4,EX24;
EX21  GOON,1;
      ACT,,XX(61),N21;
      ACT,,1-XX(61);
      TERM;
EX22  GOON,1;
      ACT,,XX(62),N21;
      ACT,,1-XX(62);
      TERM;
EX23  GOON,1;
      ACT,,XX(63),N21;
      ACT,,1-XX(63);
      TERM;
EX24  GOON,1;
      ACT,,XX(64),N21;
      ACT,,1-XX(64);
      TERM;
;
;                                END OF NODE 2
;
; ** NODE 3 **
;
EX3   ASSIGN,ATRIB(2)=ATRIB(5);
      GOON,1;
      ACT,,ATRIB(4).EQ.1,EX31;
      ACT,,ATRIB(4).EQ.2,EX32;
      ACT,,ATRIB(4).EQ.3,EX33;
      ACT,,ATRIB(4).EQ.4,EX34;
EX31  GOON,1;
      ACT,,XX(61),N31;
      ACT,,1-XX(61);
      TERM;
EX32  GOON,1;
```

```
      ACT,,XX(62),N31;
      ACT,,1-XX(62);
      TERM;
EX33  GOON,1;
      ACT,,XX(63),N31;
      ACT,,1-XX(63);
      TERM;
EX34  GOON,1;
      ACT,,XX(64),N31;
      ACT,,1-XX(64);
      TERM;
;
;                                     END OF NODE 3
;
; ** NODE 4 **
;
EX4   ASSIGN,ATRIB(2)=ATRIB(5);
      GOON,1;
      ACT,,ATRIB(4).EQ.1,EX41;
      ACT,,ATRIB(4).EQ.2,EX42;
      ACT,,ATRIB(4).EQ.3,EX43;
      ACT,,ATRIB(4).EQ.4,EX44;
EX41  GOON,1;
      ACT,,XX(61),N41;
      ACT,,1-XX(61);
      TERM;
EX42  GOON,1;
      ACT,,XX(62),N41;
      ACT,,1-XX(62);
      TERM;
EX43  GOON,1;
      ACT,,XX(63),N41;
      ACT,,1-XX(63);
      TERM;
EX44  GOON,1;
      ACT,,XX(64),N41;
```

```
      ACT,,1-XX(64);
      TERM;
;
;                              END OF NODE 4
;
; ** NODE 5 **
;
EX5   ASSIGN,ATRIB(2)=ATRIB(5);
      GOON,1;
      ACT,,ATRIB(4).EQ.1,EX51;
      ACT,,ATRIB(4).EQ.2,EX52;
      ACT,,ATRIB(4).EQ.3,EX53;
      ACT,,ATRIB(4).EQ.4,EX54;
EX51  GOON,1;
      ACT,,XX(61),N51;
      ACT,,1-XX(61);
      TERM;
EX52  GOON,1;
      ACT,,XX(62),N51;
      ACT,,1-XX(62);
      TERM;
EX53  GOON,1;
      ACT,,XX(63),N51;
      ACT,,1-XX(63);
      TERM;
EX54  GOON,1;
      ACT,,XX(64),N51;
      ACT,,1-XX(64);
      TERM;
;
;                              END OF NODE 5
;
;                              END OF RESPONSE TRAFFIC
;
;                   END OF EXTERNAL EFFECTS
;
```

```
        ENDNETWORK;
;
;                        END OF NETWORK DESCRIPTION
;
;----------------------------------------------------------------
;
INIT,0;                                   START AT TIME 0.0 SEC
;
; QUEUE PRECEDENCE IS BASED ON ATTRIBUTE 4.  LOWEST VALUE OF
;  ATTRIBUTE 4 GOES FIRST.
PRIORITY/1,LVF(4)/2,LVF(4)/3,LVF(4)/4,LVF(4)/5,LVF(4);
PRIORITY/6,LVF(4)/7,LVF(4)/8,LVF(4)/9,LVF(4)/10,LVF(4);
PRIORITY/11,LVF(4)/12,LVF(4);
;
; RUN NUMBER ONE
; RHO=0.1, 31.5 MSG/MIN
MONTR,CLEAR,1500.;                      DISCARD WARM-UP PERIOD
SIMULATE;
```
1

S L A M   S U M M A R Y   R E P O R T

SIMULATION PROJECT FULL MODEL P24B   BY BERT GARCIA

DATE 2/25/1985   RUN NUMBER 1 OF 5

CURRENT TIME .1519E+05
STATISTICAL ARRAYS CLEARED AT TIME .1500E+04

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TIS TOT	.6766E+01	.5261E+01	.7776E+00	.1418E+01	.4663E+02	9002
TIS PR 1	.6558E+01	.4879E+01	.7440E+00	.1418E+01	.3647E+02	1386
TIS PR 2	.6580E+01	.5124E+01	.7787E+00	.1418E+01	.3582E+02	1122
TIS PR 3	.6838E+01	.5293E+01	.7741E+00	.1418E+01	.4042E+02	2867
TIS PR 4	.6845E+01	.5414E+01	.7909E+00	.1418E+01	.4663E+02	3627
OVR 12		NO VALUES RECORDED				
OVR 13		NO VALUES RECORDED				
OVR 14		NO VALUES RECORDED				
OVR 15		NO VALUES RECORDED				
OVR 21		NO VALUES RECORDED				
OVR 23		NO VALUES RECORDED				
OVR 31		NO VALUES RECORDED				
OVR 32		NO VALUES RECORDED				
OVR 34		NO VALUES RECORDED				
OVR 41		NO VALUES RECORDED				
OVR 43		NO VALUES RECORDED				
OVR 51		NO VALUES RECORDED				

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	.0644	.2980	4	0	.9547
2	AWAIT	.0573	.2777	4	0	.9121
3	AWAIT	.0516	.2499	3	0	.7791
4	AWAIT	.0408	.2456	3	0	.2880
5	AWAIT	.0463	.2576	4	0	.7289
6	AWAIT	.0574	.2681	4	0	.8738
7	AWAIT	.0691	.3294	6	0	1.0331
8	AWAIT	.0822	.3420	4	0	1.2843
9	AWAIT	.0652	.2984	4	0	.9976
10	AWAIT	.0595	.2748	3	0	.9135
11	AWAIT	.0815	.3385	3	0	1.1996
12	AWAIT	.0313	.2275	5	0	.2350
13	CALENDAR	23.7434	1.8069	32	23	1.5692

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION
1	LINK12	1	.2669	.4423	1	0
2	LINK13	1	.2435	.4292	1	0
3	LINK14	1	.2715	.4448	1	0
4	LINK15	2	.5691	.7078	2	2
5	LINK21	1	.2585	.4378	1	0
6	LINK23	1	.2654	.4416	1	0
7	LINK31	1	.2601	.4387	1	0
8	LINK32	1	.2644	.4410	1	1
9	LINK34	1	.2664	.4421	1	0
10	LINK41	1	.2630	.4403	1	0
11	LINK43	1	.2834	.4507	1	0
12	LINK51	2	.5298	.6840	2	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	LINK12	1	.7331	0	1
2	LINK13	1	.7565	0	1
3	LINK14	1	.7285	0	1
4	LINK15	0	1.4309	0	2
5	LINK21	1	.7415	0	1
6	LINK23	1	.7346	0	1
7	LINK31	1	.7399	0	1
8	LINK32	0	.7356	0	1
9	LINK34	1	.7336	0	1
10	LINK41	1	.7370	0	1
11	LINK43	1	.7166	0	1
12	LINK51	2	1.4702	0	2

1

```
;
; RUN NUMBER TWO
; RHO=0.2, 63 MSG/MIN
INTLC,
          XX(11)=19.047619,
          XX(12)=19.047619,
          XX(13)=19.047619,
          XX(14)=19.047619,
          XX(15)=19.047619,
          XX(16)=19.047619,
          XX(17)=19.047619,
          XX(18)=19.047619,
          XX(19)=19.047619,
          XX(20)=19.047619;
MONTR,CLEAR,750.;
SIMULATE;
```

1

S L A M   S U M M A R Y   R E P O R T

SIMULATION PROJECT FULL MODEL P24B   BY BERT GARCIA

DATE 2/25/1985   RUN NUMBER 2 OF 5

CURRENT TIME .7740E+04
STATISTICAL ARRAYS CLEARED AT TIME .7500E+03

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TIS TOT	.9016E+01	.7594E+01	.8423E+00	.1418E+01	.1054E+03	9038
TIS PR 1	.7718E+01	.5290E+01	.6854E+00	.1418E+01	.3803E+02	1474
TIS PR 2	.8050E+01	.5802E+01	.7207E+00	.1418E+01	.4778E+02	1118
TIS PR 3	.8334E+01	.6225E+01	.7469E+00	.1418E+01	.4144E+02	2724
TIS PR 4	.1032E+02	.9355E+01	.9067E+00	.1418E+01	.1054E+03	3722
OVR 12		NO VALUES RECORDED				
OVR 13		NO VALUES RECORDED				
OVR 14		NO VALUES RECORDED				
OVR 15		NO VALUES RECORDED				
OVR 21		NO VALUES RECORDED				
OVR 23		NO VALUES RECORDED				
OVR 31		NO VALUES RECORDED				
OVR 32		NO VALUES RECORDED				
OVR 34		NO VALUES RECORDED				
OVR 41		NO VALUES RECORDED				
OVR 43		NO VALUES RECORDED				
OVR 51		NO VALUES RECORDED				

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	.3366	.7091	5	0	2.5385
2	AWAIT	.2964	.7244	5	0	2.4345
3	AWAIT	.3781	.8352	8	1	2.8265
4	AWAIT	.3968	.9394	8	0	1.4066
5	AWAIT	.4109	.8530	6	0	3.0142
6	AWAIT	.3872	.8289	7	0	3.0244
7	AWAIT	.2516	.6545	7	0	2.1372
8	AWAIT	.3850	.7988	6	0	2.8566
9	AWAIT	.3424	.7987	6	5	2.6333
10	AWAIT	.4955	1.1244	7	0	3.8488
11	AWAIT	.3559	.8188	6	0	2.7890
12	AWAIT	.2557	.7897	8	1	1.0038
13	CALENDAR	27.3501	2.0079	35	27	.9197

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION
1	LINK12	1	.5402	.4984	1	0
2	LINK13	1	.4868	.4998	1	0
3	LINK14	1	.5374	.4986	1	1
4	LINK15	2	1.1243	.8205	2	1
5	LINK21	1	.5441	.4981	1	1
6	LINK23	1	.5232	.4995	1	1
7	LINK31	1	.4704	.4991	1	0
8	LINK32	1	.5508	.4974	1	0
9	LINK34	1	.5103	.4999	1	1
10	LINK41	1	.5283	.4992	1	0
11	LINK43	1	.5069	.5000	1	0
12	LINK51	2	1.0253	.8134	2	2

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	LINK12	1	.4598	0	1
2	LINK13	1	.5132	0	1
3	LINK14	0	.4626	0	1
4	LINK15	1	.8757	0	2
5	LINK21	0	.4559	0	1
6	LINK23	0	.4768	0	1
7	LINK31	1	.5296	0	1
8	LINK32	1	.4492	0	1
9	LINK34	0	.4897	0	1
10	LINK41	1	.4717	0	1
11	LINK43	1	.4931	0	1
12	LINK51	0	.9747	0	2

1

```
;
; RUN NUMBER THREE
; RHO=0.3, 94.5 MSG/MIN
INTLC,
            XX(11)=12.698413,
            XX(12)=12.698413,
            XX(13)=12.698413,
            XX(14)=12.698413,
            XX(15)=12.698413,
            XX(16)=12.698413,
            XX(17)=12.698413,
            XX(18)=12.698413,
            XX(19)=12.698413,
            XX(20)=12.698413;
MONTR,CLEAR,500.;
SIMULATE;
```

1

S L A M   S U M M A R Y   R E P O R T

SIMULATION PROJECT FULL MODEL P24B   BY BERT GARCIA

DATE 2/25/1985   RUN NUMBER 3 OF 5

CURRENT TIME .5090E+04
STATISTICAL ARRAYS CLEARED AT TIME .5000E+03

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TIS TOT	.1974E+02	.2361E+02	.1196E+01	.1418E+01	.1935E+03	9056
TIS PR 1	.9125E+01	.6044E+01	.6623E+00	.1418E+01	.3641E+02	1410
TIS PR 2	.1037E+02	.7139E+01	.6888E+00	.1418E+01	.5061E+02	1133
TIS PR 3	.1285E+02	.1007E+02	.7834E+00	.1418E+01	.6187E+02	2853
TIS PR 4	.3210E+02	.3178E+02	.9900E+00	.1418E+01	.1935E+03	3660
OVR 12		NO VALUES RECORDED				
OVR 13		NO VALUES RECORDED				
OVR 14		NO VALUES RECORDED				
OVR 15		NO VALUES RECORDED				
OVR 21		NO VALUES RECORDED				
OVR 23		NO VALUES RECORDED				
OVR 31		NO VALUES RECORDED				
OVR 32		NO VALUES RECORDED				
OVR 34		NO VALUES RECORDED				
OVR 41		NO VALUES RECORDED				
OVR 43		NO VALUES RECORDED				
OVR 51		NO VALUES RECORDED				

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	3.4625	3.8357	16	0	16.8521
2	AWAIT	1.9199	2.6393	14	0	10.2106
3	AWAIT	1.9328	2.4967	12	0	9.7588
4	AWAIT	2.7726	3.7499	18	4	6.5798
5	AWAIT	2.4511	2.9506	14	1	12.2281
6	AWAIT	2.5016	2.7166	14	2	12.4527
7	AWAIT	1.3002	1.7604	10	0	6.9226
8	AWAIT	1.7902	2.2563	11	4	9.0888
9	AWAIT	2.4510	3.6211	16	2	12.6965
10	AWAIT	2.4364	2.7880	15	3	12.0498
11	AWAIT	2.1103	2.6652	11	0	10.8219
12	AWAIT	2.3948	3.1143	17	1	6.0693
13	CALENDAR	31.3906	1.6915	37	32	.6931

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION
1	LINK12	1	.8289	.3766	1	0
2	LINK13	1	.7673	.4226	1	1
3	LINK14	1	.8165	.3871	1	1
4	LINK15	2	1.7018	.5958	2	2
5	LINK21	1	.8222	.3823	1	1
6	LINK23	1	.8471	.3599	1	1
7	LINK31	1	.7561	.4294	1	1
8	LINK32	1	.7894	.4077	1	1
9	LINK34	1	.7994	.4004	1	1
10	LINK41	1	.8255	.3796	1	1
11	LINK43	1	.7966	.4026	1	0
12	LINK51	2	1.6306	.6474	2	2

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	LINK12	1	.1711	0	1
2	LINK13	0	.2327	0	1
3	LINK14	0	.1835	0	1
4	LINK15	0	.2982	0	2
5	LINK21	0	.1778	0	1
6	LINK23	0	.1529	0	1
7	LINK31	0	.2439	0	1
8	LINK32	0	.2106	0	1
9	LINK34	0	.2006	0	1
10	LINK41	0	.1745	0	1
11	LINK43	1	.2034	0	1
12	LINK51	0	.3634	0	2

1

```
;
; RUN NUMBER FOUR
; RHO=0.4, 126 MSG/MIN
INTLC,
           XX(11)=9.523810,
           XX(12)=9.523810,
           XX(13)=9.523810,
           XX(14)=9.523810,
           XX(15)=9.523810,
           XX(16)=9.523810,
           XX(17)=9.523810,
           XX(18)=9.523810,
           XX(19)=9.523810,
           XX(20)=9.523810;
MONTR,CLEAR,325.;
SIMULATE;
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1

S L A M   S U M M A R Y   R E P O R T

SIMULATION PROJECT FULL MODEL P24B   BY BERT GARCIA

DATE 2/25/1985   RUN NUMBER 4 OF 5

CURRENT TIME .4123E+04
STATISTICAL ARRAYS CLEARED AT TIME .3250E+03

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TIS TOT	.7130E+02	.9119E+02	.1279E+01	.1419E+01	.5324E+03	9231
TIS PR 1	.9817E+01	.5904E+01	.6014E+00	.1419E+01	.3380E+02	1481
TIS PR 2	.1144E+02	.7792E+01	.6811E+00	.1435E+01	.7098E+02	1145
TIS PR 3	.1551E+02	.1104E+02	.7119E+00	.1596E+01	.8923E+02	2913
TIS PR 4	.1585E+03	.8926E+02	.5630E+00	.1518E+01	.5324E+03	3692
OVR 12	.2412E+02	.2426E+02	.1006E+01	.4288E+00	.5599E+02	4
OVR 13	.1096E+03	.3795E+03	.3462E+01	.5719E+00	.1531E+04	16
OVR 14	.5598E+02	.1444E+03	.2579E+01	.3929E+00	.5920E+03	17
OVR 15	.2747E+02	.1204E+03	.4383E+01	.3686E-02	.1078E+04	124
OVR 21	.6340E+02	.2263E+03	.3569E+01	.1322E+00	.1356E+04	38
OVR 23	.2865E+02	.6856E+02	.2393E+01	.4883E-01	.5911E+03	107
OVR 31	.6388E+02	.1876E+03	.2936E+01	.9643E-01	.9806E+03	35
OVR 32	.4928E+02	.1228E+03	.2493E+01	.4415E+00	.4275E+03	12
OVR 34		NO VALUES RECORDED				
OVR 41	.2793E+02	.6843E+02	.2450E+01	.4159E-01	.4305E+03	116
OVR 43		NO VALUES RECORDED				
OVR 51	.2204E+02	.4904E+02	.2225E+01	.9029E-03	.3409E+03	149

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	10.2873	6.6839	25	17	40.4009
2	AWAIT	11.2751	6.6114	25	6	45.5524
3	AWAIT	11.9543	6.8004	25	23	49.7247
4	AWAIT	17.2197	5.1849	25	24	34.4546
5	AWAIT	13.3612	7.2497	25	12	53.4121
6	AWAIT	21.1265	3.0477	25	18	85.3529
7	AWAIT	15.6100	6.5324	25	14	61.5592
8	AWAIT	10.3123	7.4350	25	17	41.4419
9	AWAIT	8.1478	5.9228	23	11	33.7433
10	AWAIT	19.6647	4.3257	25	9	77.7917
11	AWAIT	7.3328	4.8642	22	10	29.5309
12	AWAIT	19.2712	5.0130	25	5	39.0532
13	CALENDAR	33.8154	.4449	37	34	.5934

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION
1	LINK12	1	.9868	.1142	1	1
2	LINK13	1	.9791	.1431	1	1
3	LINK14	1	.9795	.1418	1	1
4	LINK15	2	2.0000	.0000	2	2
5	LINK21	1	.9828	.1300	1	1
6	LINK23	1	1.0000	.0000	1	1
7	LINK31	1	.9965	.0591	1	1
8	LINK32	1	.9735	.1607	1	1
9	LINK34	1	.9447	.2285	1	1
10	LINK41	1	1.0000	.0000	1	1
11	LINK43	1	.9686	.1744	1	1
12	LINK51	2	2.0000	.0000	2	2

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	LINK12	0	.0132	0	1
2	LINK13	0	.0209	0	1
3	LINK14	0	.0205	0	1
4	LINK15	0	.0000	0	0
5	LINK21	0	.0172	0	1
6	LINK23	0	.0000	0	0
7	LINK31	0	.0035	0	1
8	LINK32	0	.0265	0	1
9	LINK34	0	.0553	0	1
10	LINK41	0	.0000	0	0
11	LINK43	0	.0314	0	1
12	LINK51	0	.0000	0	0

1

```
;
; RUN NUMBER FIVE
; RHO=0.5, 158 MSG/MIN
INTLC,
          XX(11)=7.619048,
          XX(12)=7.619048,
          XX(13)=7.619048,
          XX(14)=7.619048,
          XX(15)=7.619048,
          XX(16)=7.619048,
          XX(17)=7.619048,
          XX(18)=7.619048,
          XX(19)=7.619048,
          XX(20)=7.619048;
MONTR,CLEAR,200.;
SIMULATE;
```

1

SLAM SUMMARY REPORT

SIMULATION PROJECT FULL MODEL P24B   BY BERT GARCIA

DATE 2/25/1985   RUN NUMBER 5 OF 5

CURRENT TIME .4116E+04
STATISTICAL ARRAYS CLEARED AT TIME .2000E+03

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TIS TOT	.1025E+03	.1232E+03	.1202E+01	.1437E+01	.5973E+03	9531
TIS PR 1	.9759E+01	.6022E+01	.6171E+00	.1584E+01	.4197E+02	1471
TIS PR 2	.1051E+02	.6983E+01	.6645E+00	.1437E+01	.5617E+02	1147
TIS PR 3	.1441E+02	.1041E+02	.7222E+00	.1457E+01	.8769E+02	2932
TIS PR 4	.2281E+03	.9542E+02	.4184E+00	.1853E+01	.5973E+03	3981
OVR 12	.3159E+02	.1115E+03	.3531E+01	.2570E-01	.1006E+04	108
OVR 13	.2359E+02	.5392E+02	.2286E+01	.1047E-01	.3255E+03	154
OVR 14	.6059E+02	.2171E+03	.3584E+01	.4167E-01	.1645E+04	59
OVR 15	.1509E+02	.3458E+02	.2291E+01	.4462E-02	.2608E+03	252
OVR 21	.1764E+02	.6375E+02	.3614E+01	.6959E-02	.7537E+03	213
OVR 23	.1347E+02	.3035E+02	.2253E+01	.3135E-01	.2358E+03	280
OVR 31	.1773E+02	.3469E+02	.1957E+01	.2384E-01	.2512E+03	216
OVR 32	.2744E+02	.9426E+02	.3435E+01	.1930E-01	.8434E+03	105
OVR 34	.2336E+02	.6381E+02	.2732E+01	.9158E-03	.5543E+03	151
OVR 41	.1779E+02	.4502E+02	.2530E+01	.2927E-02	.3904E+03	220
OVR 43	.1448E+02	.4032E+02	.2785E+01	.8754E-02	.4619E+03	258
OVR 51	.9583E+01	.2416E+02	.2522E+01	.2315E-02	.2778E+03	409

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	18.6933	5.7692	25	20	74.3945
2	AWAIT	21.5424	3.5896	25	22	87.6938
3	AWAIT	16.6497	6.5642	25	16	64.5558
4	AWAIT	21.1174	3.1953	25	24	42.3655
5	AWAIT	20.9416	4.1469	25	25	83.3425
6	AWAIT	22.3028	2.8177	25	24	89.9477
7	AWAIT	22.4283	2.2061	25	22	86.8754
8	AWAIT	18.0774	5.7808	25	9	73.9731
9	AWAIT	20.6124	4.1971	25	22	83.3879
10	AWAIT	21.9962	2.8993	25	25	86.2251
11	AWAIT	22.3862	2.8304	25	24	88.2841
12	AWAIT	21.7044	3.0831	25	25	43.1015
13	CALENDAR	33.9916	.1269	37	35	.5661

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION
1	LINK12	1	1.0000	.0000	1	1
2	LINK13	1	1.0000	.0000	1	1
3	LINK14	1	.9877	.1104	1	1
4	LINK15	2	2.0000	.0000	2	2
5	LINK21	1	1.0000	.0000	1	1
6	LINK23	1	1.0000	.0000	1	1
7	LINK31	1	1.0000	.0000	1	1
8	LINK32	1	1.0000	.0000	1	1
9	LINK34	1	1.0000	.0000	1	1
10	LINK41	1	1.0000	.0000	1	1
11	LINK43	1	1.0000	.0000	1	1
12	LINK51	2	2.0000	.0000	2	2

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	LINK12	0	.0000	0	0
2	LINK13	0	.0000	0	0
3	LINK14	0	.0123	0	1
4	LINK15	0	.0000	0	0
5	LINK21	0	.0000	0	0
6	LINK23	0	.0000	0	0
7	LINK31	0	.0000	0	0
8	LINK32	0	.0000	0	0
9	LINK34	0	.0000	0	0
10	LINK41	0	.0000	0	0
11	LINK43	0	.0000	0	0
12	LINK51	0	.0000	0	0

```
—EOR—
1 YBLR    (01) * ASD COMPUTER CENTER NOS CSB *.   NOS 2.2-605/587.    19.56.47. 85/02/26.

 19.48.12.GARCIA,STCSB.
 19.48.12.USER(T841239,)
 19.48.12.CHARGE,*.
 19.48.12.* CHARGE(T841239,T841239)
 19.48.14.$PROLOG,PROC1,,.
 19.48.14.$SETFS,PROC1/FS=AD.
 19.48.14.PROC1.
 19.48.15.NOTE(OUTPUT,NR)+ WELCOME TO NOS 2.2
 19.48.15.IFE($$.NE.$$,NOUP)
 19.48.15.ENDIF(NOUP)
 19.48.15.RETURN,PROC1.
 19.48.15.$REVERT.CCL
 19.48.15.COPYBF,INPUT,TAPE5.
 19.48.15. COPY COMPLETE.
 19.48.15.REWIND,TAPE5.
 19.48.15.GET,SLAMB.
 19.48.15.SETTL(5000).
```

```
19.48.16.FTN5,I=SLAMB,ANSI=0,L=0.
19.48.16.      56100 CM STORAGE USED.
19.48.16.      0.041 CP SECONDS COMPILATION TIME.
19.48.16.ATTACH,SLAMLIB/UN=APPLIB.
19.48.17.LIBRARY,SLAMLIB.
19.48.17.LGO.
19.56.46.    STOP
19.56.46.    376500 MAXIMUM EXECUTION FL.
19.56.46.   418.198 CP SECONDS EXECUTION TIME.
19.56.47.UEAD,       0.002KUNS.
19.56.47.UEPF,       0.029KUNS.
19.56.47.UEMS,      29.978KUNS.
19.56.47.UECP,     419.709SECS.
19.56.47.AESR,     995.373UNTS.
19.56.47.$OUT(*/OP=E)
19.56.47. NO FILES PROCESSED.
19.56.47.$DAYFILE(OUTPUT,JT=D)
```

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